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Diane Vaughan's analysis of the causes of the Challenger *accident suggests ways to apply science and technology studies to the teaching of engineering ethics. By sensitizing future engineers to the ongoing construction of risk during mundane engineering practice, we can better prepare them to address issues of public health, safety, and welfare before they require heroic intervention. Understanding the importance of precedents, incremental change, and fallible engineering judgment in engineering design may help them anticipate potential threats to public safety arising from routine aspects of workplace culture. We suggest modifications of both detailed case studies on engineering disasters and hypothetical, ethical dilemmas employed in engineering ethics classes. Investigating the sociotechnical aspects of engineering practice can improve the initial recognition of ethical problems in real-world settings and provide an understanding of the role of workplace organization and culture in facilitating or impeding remedial action.*

By now it is part of engineering folklore: the night before the tragic shuttle *Challenger* launch resulting in its destruction and the death of seven astronauts, engineers had identified the danger but had failed to persuade NASA to call off the flight. After Morton Thiokol presented its engineering conclusion during a second teleconference that the shuttle should not launch below 53 degrees Fahrenheit, managers at Marshall Space Flight Center and Kennedy Space Center challenged the analysis and argued that the recommendation amounted to introducing new launch commit criteria on the eve of the flight. George Hardy, Marshall's deputy director of science

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and engineering, declared himself “appalled” at the recommendation. Similarly, NASA’s Solid Rocket Booster Project Manager Larry Mulloy objected, “My God, Thiokol, when do you want me to launch, next April?” During an offline discussion among Thiokol engineers and managers in Utah, Senior Vice President Jerry Mason finally called for a “management” decision to be made. Initially, Vice President of Engineering Robert Lund had been championing the engineers’ case against launching. When Lund alone among the four managers conferring seemed to hold out, Mason told him, “It’s time to take off your engineering hat and put on your management hat.” Lund capitulated, and the launch went forward. For engineers, ethicists, and the media, this brief exchange encapsulated everything that went wrong in the shuttle program leading up to the disaster on 28 January 1986: apparently, production and schedule pressures prevailed over a concern with safety. This episode and the anecdote about engineering and management “hats” are by now so widespread in the engineering and engineering ethics literature that it comes as a shock to discover that the “schedule-over-safety” interpretation of the cause of the disaster is mistaken.

But that is just what Diane Vaughan shows in an exhaustively researched book on the process leading up to the accident. Not only does her work question the canonical interpretation of this disaster, but it also raises questions about the way engineers are taught to think about the role of ethics in engineering (Vaughan 1996, 304-5, 315-16, 318). We argue that ethicists need to pay attention to the complexities of engineering practice that shape decisions on a daily basis. Our goal in this article will be to explore how engineers can learn to identify features of their everyday practice that potentially contribute to ethically problematic outcomes before clear-cut ethical dilemmas emerge. Supplementing current emphasis in engineering ethics on moral theory and professional responsibility, our approach builds ethical reflection on the close examination of technical practice developed in science and technology studies.

Engineering Ethics as Applied Moral Philosophy

A popular textbook defines engineering ethics as “(1) the study of the moral issues and decisions confronting individuals and organizations involved in engineering; and (2) the study of related questions about moral conduct, character, policies, and relationships of people and corporations involved in technological activity” (Martin and Schinzinger 1996, 23). Ethical instruction is sometimes understood as providing a systematic guide for individual moral thinking rather than inculcating a specific set of values. Engineering educator P. Aarne Vesilind defines ethics as “the study of systematic methodologies which, when guided by individual moral values, can be useful in making value-laden decisions" (Vesilind 1998, 290). From this perspective, moral theory can help ensure that engineers act ethically.

Engineering ethics is a form of professional ethics, however, which requires reflection on the specific social role of engineers. One recent textbook emphasizes that

> engineering ethics is a type of professional ethics and as such must be distinguished from personal ethics and from the ethical obligations one may have as an occupant of other social roles. Engineering ethics is concerned with the question of what the standards in engineering ethics should be and how to apply these standards to particular situations. (Harris, Pritchard, and Rabins 1995, 14)

By emphasizing the ethical obligations of engineering as a profession, this current approach aims to ensure that engineers meet their obligation to the public—often formalized in the codes of ethics of professional engineering societies—regardless of any pressures they may encounter working in a corporate environment. Whether emphasizing individual moral reasoning or professionally normative standards, engineering ethicists have been particularly concerned to help ensure that the engineer will resist social pressures on the job.

Textbooks in engineering ethics cover a number of issues facing engineers, including avoiding conflicts of interest, protecting trade secrets and confidentiality, right to dissent, professional responsibility, and the obligation to protect public safety, health, and welfare. Our focus is on the last of these moral issues, protecting public safety, which we feel can benefit from a more sustained engagement with engineering practice. We believe that an understanding of moral theory and a recognition of the importance of professional codes of ethics are important components of engineering ethics instruction. However, mitigating potential threats to public safety requires engineers to reflect on the way workplace practices shape routine decisions that may lead to undesirable outcomes. Knowing what to do—whether by practicing autonomous moral reasoning or by following professional codes of conduct—may be insufficient to prevent harm if the engineer is not skilled in recognizing potential problems.[1]

The use of moral theory and the application of professional standards of conduct help engineering students to recognize moral problems and decide what ought to be done. We argue that for most of the issues raised in engineering ethics classes, this approach works well. However, when applied to questions of public safety in which engineers are salaried employees of corporations or other bureaucratic organizations, the focus on individual or professional autonomy can lead to an excessive focus on the conflict between engineers and management, potentially leading to whistle-blowing by the engineer. Since corporations are profit-oriented enterprises, managers acting on behalf of corporate interests are assumed to engage in cost-benefit analysis that may lead to decisions that value safety less than engineers' professional responsibility would require. Consequently, engineering ethics focuses heavily on the conflict between management's cost-benefit calculations and the engineer's commitment to public safety. Asserting the engineer's rights of conscientious refusal and professional dissent from management and suggesting how to go beyond whistle-blowing then become the focus of discussion, and the complex ways in which engineering judgments of acceptable risk themselves are shaped by engineering practice and institutional culture are ignored.

In engineering ethics teaching, there has been a good deal of movement away from debating whether whistle-blowing can be justified by arguments employing moral theory (Weil 1983). Martin and Schinzinger (1996, chap. 6), in a section of their textbook titled "Beyond Whistleblowing," argue that engineers should first pursue remedies short of whistle-blowing within the organization, reserving whistle-blowing for a last resort. Their emphasis on the right of engineers to conscientious dissent still frames the debate in terms of a conflict between engineering and management, however, just as in the earlier debate over whistle-blowing. Nevertheless, their emphasis on the rights and duties of engineers in corporate settings calls attention to the importance of the social context in which ethical decisions get made. Echoing a trend in applied ethics more generally, engineering ethics has seen a revival of casuistry, or case-based reasoning.[2] Beginning with agreed-on examples of right and wrong actions in particular cases, casuistry requires comparing more problematic cases to determine possible courses of action. While such cases provide more concreteness in thinking about ethical issues in engineering, they share with the focus on whistle-blowing a selective focus: only particular actions by individual moral agents are considered. Hypothetical cases used by engineering ethicists focus typically on the actions of an individual engineer facing a moral dilemma, without providing a detailed account of workplace routines, the past history of related decisions, resources available to the engineer, or the actions of other agents facing similar issues.

Expanding Casuistry

Drawing on the analysis of embedded technical practice developed in the interdisciplinary field of science and technology studies (Jasanoff et al. 1995), we wish to expand casuistry's focus to include more *actions* and more *agents*. Moral choices are made continuously within a stream of ongoing practice, while a variety of different agents with varied interests and experiences shape decision making. Instead of fixating on dramatic cases of whistle-blowing or idealized cases of moral conflict, we argue that ethicists need to pay attention to the complexities of engineering practice that shape decisions on a daily basis. In this respect, we build on Harris, Pritchard, and Rabins's (1995) emphasis on "preventative ethics" and the need to find a "creative middle way" as well as Martin and Schinzinger's (1996) account of engineering as a "social experiment," which calls for consideration of the social consequences of engineering practice and the need to learn from experience.[3]

Vaughan (1996) shows us that we need to focus on how engineers understand and manage risk on a day-to-day basis; if we do that, we will see that a process of incremental adjustment to altered safety standards takes place that appears rational at every stage of the process—every stage, that is, until the legacy of established precedents ties the hands of those engineers who see too late what is happening. For Vaughan, would-be ethical engineers may be hamstrung less by dishonest management than they are by their own prior history of attempts to determine the acceptable risk of an inherently risky and novel technology—although it is certainly true that larger structures of institutional secrecy and an emphasis on production reinforce these decisions. What Vaughan objects to is the analytical short circuit that couples the existence of production and schedule pressures with a fateful decision that certain risks were acceptable, leading the analyst to conclude that engineers or managers cynically accepted conditions they recognized were unsafe—an influential caricature of the decision making behind many engineering disasters that Vaughan dubs "amoral calculation."[4]

What relevance does this debate about the causes of the *Challenger* accident have for how engineers should reflect on the ethical consequences of their actions? Engineering ethicists usually assume that the primary obstacle that engineers face in acting ethically in promoting public safety in organizations is amoral calculation—whether in themselves or in their managers. The trick then becomes to embolden the engineer to resist this amoral calculation, whether it be by an infusion of moral theory or by inspiring tales of moral heroism or by an emphasis on what professional codes of conduct require. An emphasis on heroic resistance creates an unfortunate dichotomy in the debate over whistle-blowing, as evidenced in a volume titled *Beyond Whistleblowing* (Weil 1983). Whereas Alpern (1983) suggests that those entering the engineering profession should be prepared to meet their moral duty to engage in heroic acts of resistance if necessary, Florman (1983) argues that one cannot rely on individual moral responsibility to avoid engineering disasters but should depend on government regulation. This either/or scenario—either heroic, individual moral action or no professional, ethical responsibility at all—depends on viewing ethics as an individual act, ignoring the incubation period leading up to moral dilemmas and the possibility of organizational and collective ethical responses to moral problems. Hence, the anthology's reference to getting "beyond whistle-blowing" reduces to getting beyond ethics altogether for Florman, although the introduction to the collection stresses the need to expand the concern with whistle-blowing to considering ways to promote professional independence within the context of bureaucratic work environments.

What is presumed to be less problematic is identifying which practices potentially threaten public safety and welfare: corporate evil will enter the stage like Darth Vader, and all the budding engineer needs to know is when and how he or she should resist. Readers who question whether this picture is a caricature should reflect on the cult of personality that has built up around certain whistle-blowers, including notably "near whistle-blowers" who did not in fact prevent the disasters they warned about. Thiokol engineer Roger Boisjoly comes to mind, as does Rachel Carson, whose warnings about toxins in the environment arguably remain insufficiently heeded.[5] While we find the actions of figures such as these commendable and indeed heroic, building a reform movement on heroic figures has significant dangers, among them that these are often tragic figures who rarely inspire students to wish to emulate their lives and that what attracts notice is the individual's resistance—and hence personal moral integrity—rather than their practical success in overcoming the problem.[6]

Other commentators notice that individual acts of resistance do not happen in a vacuum and that students should be encouraged to find out what resources are available inside and outside the company to assist the engineer.[7] Stephen Unger (1994), for example, considers the role that engineering societies, codes of ethics, engineering unions, lawyers, regulatory agencies, and internal procedures can play in supporting the dissenting engineer. Still, the focus remains on institutional and collective resources that can help bolster the autonomy of the individual engineer (Unger 1994, chaps. 4-7). Harris, Pritchard, and Rabins (1995, 68-76) speak about "impediments to responsibility," spending the least amount of discussion on ignorance, which is attributed to either "willful avoidance" or "a lack of persistence." But what too often happens is that by the time engineers recognize the severity of the problem, precedents have been established and a workplace culture has evolved based on a set of assumptions that rationalizes the flawed course of action. Engineering ethics courses should be less oriented toward simulating either petty (or large-scale) dramas of right and wrong than helping engineers to reflect on aspects of their engineering workplace practices that do not manifestly involve ethical concerns but that may—if the practices continue as they are or if new scenarios develop—lead to ethically questionable outcomes. In anticipating potential threats to public safety, engineers should not rely on abstract moral philosophy exclusively but also draw on the in vivo study of technical practice by social scientists and historians, now embraced by the label *science and technology studies* (including a focus on interpretative flexibility and closure, trust in numbers, and unruly technology) (Downey and Lucena 1995; Collins 1985; Porter 1995; Wynne 1988).

At least since the work of Robert Merton, the sociology of science has suggested that the identification of the remote ethical consequences of a practice require explicitly sociological reflection and may not be evident in the flow of unreflective practice (Merton 1979). Recent ethnographic and sociological approaches have shown how microcultural constructions of knowledge about natural and social phenomena are built up by the ongoing, mundane, sense-making activities of participants, so that retrospective judgments by philosophers risk ignoring the reasons why signals of danger were recognizable or not at the time. In other words, commentators too often fail to consider how scientific and engineering contexts would appear to participants themselves; this, in turn, facilitates an unproductive moralism relying on the benefit of hindsight for its seeming effectiveness.[8] Vaughan (1996) draws on this work in science and technology studies in presenting a detailed "historical ethnography" of the development of the understanding of risk by the group of engineers concerned with monitoring the design of the solid rocket boosters and the troubled O-rings. At the same time, she tries to keep the larger structural constraints on practice in view—the engineers' "production of culture" was reinforced by NASA's "culture of production" and "structural secrecy."[9] In addition, she traces how the internally coherent and rational constructions of risk developed by the engineers intersected with various contingencies to result in an overall objectionable outcome, a process she calls the "normalization of deviance." Figuring out how to avoid such normalization is not easily determined but certainly seems to require considering how early decisions may help legitimize later ones and how incremental change may lead to constructions of acceptable risk that would not have otherwise been accepted. Our goal in this article will be to explore how engineers can be sensitized to these elements of engineering practices and develop strategies for addressing potential dangers before they require heroic intervention.

Since work in science and technology studies emphasizes the local integrity of practices, it often refuses to consider the limitations, failures, or pathologies of cultural practices (Lynch 1994). In a section titled "The Inevitability of Mistake," Vaughan (1996, 415-22) herself is skeptical that any structural changes are likely to anticipate future mistakes or avoid interfering with elements of the organization that currently function well in preventing disaster. The problem with this way of looking at the issue is that the entire burden is placed on sociologists or other outsiders to reform organizational practices (since Vaughan rejects the scapegoating of particular individuals as a solution).[10] Instead, we suggest that science and technology studies can provide conceptual tools that would empower engineers to identify problematic features of their own practice and exercise their own imagination—individually and collectively—to develop strategies for dealing with these problems. There is an important theoretical insight here since engineers may be well placed to shape the form of the technologies that come into existence by the design choices they make available to otherwise more "powerful" actors (Latour 1996; Boland 1983). We turn now to consider how Vaughan's alternative analysis of the *Challenger* accident suggests a different strategy for engineering ethics research and teaching.

Avoiding Brinkmanship Ethics

Robert Lund's replacement of his engineering hat for his management hat has served as a mythic moment in the history of engineering ethics. Like most myths, the meanings attributed to this event serve more to reinforce complacency with the status quo than to encourage serious soul searching and institutional reform. The mood and tense of the myth are past perfect subjunctive: the ethicist focuses on what should have been, using the tools of what any reasonable, informed engineer should have had at his or her disposal. For many engineers, understandably, the desirable state of affairs would be one in which the engineers got to make the decision, in which they had autonomy from meddling managers. Writing for the Institute of Electrical and Electronics Engineers' *IEEE Spectrum*, science journalists Trudy E. Bell and Karl Esch (1987, 38) distinguished sharply between "managers" who were agreed that redundancy of O-rings would be maintained and the engineers, among whom "not one . . . supported a decision to launch." As we will see, just what was the engineers' attitude, apart from Roger Boisjoly and Arnie Thompson, is difficult to tell since the response to the management decision was silence. Moreover, "management" were also engineers and evaluated (so they thought) the strength of the engineering analysis before making their decision.

> The 34 participants [in the second teleconference] did not divide cleanly into the categories "managers" and "engineers." According to Marshall's Larry Wear: "All of the people that participated in that meeting are engineers. So it's difficult to say that engineering is saying one thing and management is saying

> something else. They are all engineers and they are all engineering managers. There aren't any 'pure management people' in the whole stack. Everyone who is there is a trained engineer, has worked as a working engineer. Even though they may not be assigned to engineering organization per se, they are, by trade, engineers and by thought process engineers." (Vaughan 1996, 299-300)

The reduction of this complex decision process to a conflict of identities, however, was perhaps inevitable when the Lund anecdote came to light.

For engineering ethics textbooks, the case demonstrates the "arrogance" of managers who "pretend that factors other than engineering judgment should influence flight safety decisions" (Martin and Schinzinger 1996, 84, quoting an aerospace engineer's letter to the *Los Angeles Times*). In reflecting on the perception by Thiokol engineers that they had been forced into proving that the flight was unsafe, rather than requiring proof of safety, the authors invoke arrogance as an explanation for the disaster, suggesting that it led to a reversal of "NASA's (paraphrased) motto 'Don't fly if it cannot be shown to be safe' to 'Fly unless it can be shown not to be safe'" (Martin and Schinzinger 1996, 85). Here the hat anecdote suggests a conscious, willfully ignorant reversal of a risk-averse strategy for one serving management imperatives. A more sophisticated analysis can be found in the suggestion by Michael Davis (1991) that a code of ethics for engineers might help engineers resist abdicating their role for a contrary one. Harris, Pritchard, and Rabins (1995) distinguish a "proper engineering decision" (PED) from a "proper management decision" (PMD). A proper engineering decision is defined as

> a decision that should be made by engineers or at least governed by professional engineering practice because it involves (1) technical matters that fall within engineering expertise or (2) the ethical standards embodied in engineering codes, especially those requiring engineers to protect the health and safety of the public.

A proper management decision is one

> that should be made by managers or at least governed by management considerations because (1) it involves factors relating to the well-being of the organization, such as cost, scheduling, marketing, and employee morale or well-being; and (2) the decision does not force engineers (or other professionals) to make unacceptable compromises with their own technical practices or ethical standards (Harris, Pritchard, and Rabins 1995, 278).

Hence, from this point of view (which we will criticize below), engineering decisions can be overridden only if no threat to public safety and health results. When public safety is at stake, management's concern with the organization's needs can never override engineering judgment made on the basis of technical understanding. This conceptualization of the position of engineers in organizations suggests that the engineer's responsibility to protect public safety depends primarily on resisting any tendency for managerial concern with cost to trump engineering concern with safety, with the *Challenger* launch decision presented as an example of that danger (Harris, Pritchard, and Rabins 1995, 283-86). In each case, the fateful "management" decision was conceptualized as an alternative to engineering analysis, when it should be seen instead as an established procedure for coming to a decision when engineering consensus is not forthcoming, a procedure predicated on the hybrid engineer-manager's experienced engineering judgment.

This judgment depended on two arguments: (1) Thiokol engineers had not established a correlation between blowby and low temperature; indeed, the second most serious blowby of hot gases past the O-ring was detected on the warmest launch (75 degrees). This decision conformed to existing engineering assumptions about what good engineering analysis required and a corollary emphasis on the need for quantitative reasoning rather than subjective opinion.[11] (2) Redundancy was believed to be retained in the event of primary O-ring failure. This belief was facilitated by the confused history of belief in redundancy among the O-ring work group itself, with alternative understandings of what strict redundancy required. Thiokol's Al McDonald had noted that the cold adversely affected both O-rings but that it affected the primary one more since the normal leak check process forces the O-ring into the wrong side of the groove. Others interpreted McDonald to be suggesting that the secondary O-ring would be in a position to seal if the primary one failed, while McDonald had merely intended to note that this differential rate of sealing should be factored into any consideration of what the lowest safe temperature should be. When the four involved in the Thiokol management caucus decided to reverse Thiokol's earlier recommendation, they were each taking into account technical arguments responding to the initial analysis correlating cold temperature with blowby and questioning redundancy.

The key to reinterpreting the significance of Mason's hat analogy is situating it within an established, if often informal, practice of having management engineers come to an informed decision when consensus was not forthcoming.[12] Vaughan (1996) quotes Thiokol's Larry Sayer's interpretation of Lund's response to Mason's call to put on his management hat, an interpretation that emphasizes the lack of additional resources among the engineers for defending the negative recommendation as well as the engineering basis of the judgment:

> I could feel that he [Lund] was in a very tough position and one that he was very uncomfortable with. He turned around and looked at the people that support him that put the engineering data together, and *no one said anything*. I think he was really looking for help—is there anything else we can do *from an engineering point of view* that would make our original recommendation *strong enough that we could stand behind it*?" (P. 318, emphasis added)

The shared assumptions among "managers" and "engineers" are significant here: the engineers could offer no additional resources that could be recognized as sufficient to warrant a recommendation not to launch, so a management decision had to be made. If there is anything significant about the roles of managers and engineers in this scenario, it is that engineering judgment is reserved to managers acting in conditions of dissensus, while engineers require thorough engineering analysis (preferably quantitative and experimental) to support their case.[13]

Yet this still does not tell us why Thiokol engineers felt that they were put in the new and awkward position of having to prove that the launch would be unsafe when the established understanding held that no launch should go forward until proof of acceptable risk was obtained. From a management perspective, this was just another example of overly anxious engineers looking to stop the launch, a frequent situation that required a careful consideration of the arguments and an informed, management decision. Contrary to much well-intentioned advice, this does not mean that NASA should have stopped all such launches since this could well mean that the shuttle could not go forward. By its nature, the shuttle was a risky technology, and if the decision to develop it is made and the means to track problems are carried out, one cannot but expect that numerous potential disasters will be identified.[14] Hans Mark, a deputy director of NASA until six months before the *Challenger* disaster, reports that he participated in twelve shuttle launch decisions. In every case, some engineers opposed launch for fear that some component subsystem would fail catastrophically. Mark notes that sometimes a delay was authorized, and in other cases the launch proceeded (Mark 1987, 221-22; quoted in Pinkus et al. 1997, 312-13). Strangely, Pinkus et al. (1997, 313) treat these cases as yet another sign that engineers' legitimate autonomy was being infringed on, wondering how many more cases of failure to delay launch based on engineers' recommendations may have occurred further down the hierarchy. They seem not to consider the paralysis that would exist if any engineer's judgment could not be overturned no matter how compelling the counterargument; instead, Mark's experience is taken to attest to NASA's "low-cost," "high-risk" mentality." We should be clear that we are not arguing that NASA should not have heightened safety standards, merely that the burden of such a recommendation is to show that critics urging that engineering veto power be institutionalized as a safeguard deal with all the consequences of such a policy, including cases that did not lead to catastrophic failure but that could lead to flight cancellation. Within the stream of high-level decision making, filtering out genuine problems from less critical ones was an established procedure. Moreover, the requirements for passing information up the hierarchy were intended to make sure that all possible risks were vetted and that unpleasant information would receive a hearing. The safety review procedure was indeed designed to ensure that engineers demonstrated that systems were safe before launch authorization could proceed.

So why did engineers (especially Boisjoly) perceive that the emphasis had switched to requiring engineers to prove that the shuttle was unsafe to fly before launch would be aborted? If managers believed themselves to be following established, risk-averse procedures, if they had not cynically converted to a consciously risk-taking approach, fueled by schedule or arrogance, why did the engineers perceive a switch in emphasis? For Vaughan (1996), the answer lies in the strength and obduracy that the engineers' own culture developed as their prior decisions about acceptable risk became alienated from their own control and established themselves within NASA culture as a whole. It is the engineers themselves who had certified that the O-rings were acceptable risk, that redundancy had been maintained. Changes required that new information of risks be introduced, yet Boisjoly's attempted correlation of O-ring problems with low temperatures had been seemingly refuted. Moreover, from its perspective, NASA was following its standard rule of questioning any contractor decision, whether that decision was for or against launch. Boisjoly thought that NASA had changed from a requirement that contractors prove that the shuttle was safe to launch to one that required proof that it was unsafe to launch. In fact, NASA questioned both recommendations equally. This looked like a change in procedure to Boisjoly since Thiokol shifted from advising to launch to advising not to launch.

While it certainly would be helpful if management "listened" to their employees and took engineering judgment "seriously," whatever such platitudes mean in practice, the explanation for why managers could construe the engineers' objections as unreasonable was that the managers were relying on the engineers' own history of judgments about acceptable risk while they had effectively exploded the only new objection by the standards of proof accepted by engineering culture: the engineers had not demonstrated any quantitative correlation between temperature and O-ring blowby.[15] The engineers, meanwhile, had become convinced that their earlier confidence that the O-rings were an acceptable risk was now mistaken, but they lacked the resources accepted by engineering culture to reverse the course of action they had begun.

Classic tragedy, this unfortunate situation has subsequently been reenacted by would-be existentialists insisting that engineers take responsibility for all the consequences of their actions, however unforeseen; one gets the impression from the tone of much after-the-fact discussion that the engineers should have heroically resisted, called the press, thrown themselves in front of the path of the astronauts boarding the shuttle, or some such dramatic display of one's own personal responsibility for all the disparate consequences of one's action. Never mind that the situation would seem to have to recur on a regular basis if Mark's (1987) account of engineers' regular prophecies of doom are taken seriously. Soon, we would have not heroic whistle-blowers but the kid who cried wolf once too often. So when such dramatics do not come to pass, the vice of hindsight allows one to assume that one would have acted to avert tragedy if placed in the engineer's position without having to change anything in one's own environment. A solid grounding in moral philosophy, a personal moral code, and commitment to professional responsibility are assumed to inoculate us from that weakness of will.

Another way of avoiding tragedy is to find an external scapegoat, one who will assume all the sins of the community, thereby absolving everyone else of blame. The manager is often the preferred corrupt figure here.[16] Moreover, the manager is considered in isolation from any larger economic or sociological process leading to corrupt decisions when they exist. A demonology replaces a sociology. Clearly, the engineering profession's place within the marketplace and inside large, hierarchical organizations makes the captive nature of the profession an imperative in any analysis of engineering ethics.[17] And Vaughan (1996) does show how the cultures of secrecy and production that surround the engineering work group help explain why their microculture can be appropriated and used against them. But this recognition should result in a more sociologically sensitive ethics rather than a reduction of ethics to blaming a convenient target without considering what alternative set of circumstances would remove the inappropriate discretionary power that management, government agencies, and corporations are presumed to hold.

What can we conclude about the form our sociological ethics should take? How should engineers reflect on their practice and find ways to alter it to head off potential problems at the pass? From Vaughan's (1996) case study, a few salient features of engineering design are worth noticing: (1) Small precedents can make a large difference, and engineers should be aware that the meaning attributed to such precedents by other actors may differ from one's own. (2) Incremental changes in engineering judgments are an ordinary feature of ongoing practice; engineers should find ways to identify and reverse potentially problematic trajectories. (3) Engineering judgement is often delegitimated when quantitative proof is lacking; alternatively, a mistaken belief that one understands a certain phenomenon empirically or theoretically can lead one to "black box" problems that deserve further investigation. Engineering practice—like scientific practice—is open-ended and incomplete; mythical accounts of engineering method are potentially lethal by presuming that cognitive judgments on design safety are unproblematic.[18] These themes—the importance of precedents, incrementalism, and the simultaneous need for and fallibility of engineering judgment—can serve as better resources for identifying and responding to ethical issues in engineering involving public safety than focusing primarily on cases of apparent amoral calculation. No doubt there are cases in which amoral calculation provides a pretty good picture of decision making; however, such cases may be rarer (and less clear-cut) than engineering ethics textbooks suggest. In the remainder of this article, we will suggest strategies for incorporating an understanding of engineering practice in engineering ethics pedagogy.

Engineering Ethics in the Classroom

Engineering ethics education would be enriched by a focus on the sociological and cultural context of engineering practice. We argue that students must develop the skills necessary to identify ethically problematic elements of ordinary engineering practice when significant threats to public safety are not immediately visible. Decisions of ethical import are shaped by cultural and institutional contexts. Engineers not only produce artifacts, they help produce a set of taken-for-granted assumptions about how the practice of engineering should be carried out; they are active producers of workplace cultures that may shape decisions of interest to ethicists. But so far, little attention has been focused on how engineers could learn to notice elements of their work setting that may be of ethical significance before vexing ethical dilemmas present themselves. Consideration of how the ongoing production of culture shapes the options available to engineers facing ethical dilemmas suggests a more fruitful focus for engineering ethics, and it calls attention to a crucial skill necessary for effective ethical action: the recognition of everyday ethical problems in the first place.

Prepackaged ethical dilemmas are standard fare for courses in engineering ethics since they allow teachers to cover a case in a single class session. Typically, the student is invited to balance competing directives, such as the obligation to obey superiors and the requirement to provide accurate information on potentially serious design flaws.[19] Such a decision is usually presented in idealized fashion, without providing contextual details of established resources, practices, and rules within a given work setting. Moreover, typically a single decision point is identified; a few present a single follow-up decision, but little sense of the cumulative effect of ongoing ethical decisions on workplace culture can be gleaned from such exercises.

Educators have complained that too great an emphasis on all-or-nothing dilemmas can be disabling for students: to take the extreme case, if the only choices one is given are to challenge superiors, potentially losing one's job, or accept the status quo, potentially leading to serious, negative outcomes, students may feel that ethics involves nothing more than a pure trade-off between sacrificial heroism and amoral self-interest. Such cases may not promote the initial recognition of ethical problems in ill-structured, real-world situations, nor are they likely to give students a sense of how different elements of their work setting and culture can impede or facilitate remedial action.[20]

Getting engineers to act ethically in well-structured but ideal cases may be less important than improving their ability to identify ethically problematic issues in a poorly structured problem field within an institutionally and culturally constrained set of tacit assumptions.[21] We argue that the promotion of ethical decision making can be facilitated by developing an understanding of the sociological and cultural context of engineering practice and its effect on ongoing, mundane engineering practice. Direct, intentional conflicts of ethical values may be less important than the historically and sociologically explicable outcome of unintended consequences of intentional action and the cultural normalization of practices that would be questionable if the disparate effects of these practices could be traced.

Does university instruction in engineering ethics help ensure that engineers will act effectively to protect public safety and welfare in their future careers? We believe that the failure to focus on ordinary, ongoing engineering practice limits the likelihood that graduates will be able to identify features of their work setting that may call for ethical reflection. Vaughan (1996) traces the normality and incrementalism leading up to the *Challenger* launch decision by reconstructing the prior history of the work group of engineers and managers who addressed themselves to O-ring problems.

By undermining the picture of the “amoral calculator” that underpins the canonical interpretation of the *Challenger* accident, Vaughan (1996) also challenges similar assumptions implicitly animating much engineering ethics pedagogy. Managers are identified as calling for cost and schedule considerations to supplant the safety concerns of the engineer. For the instructor in engineering ethics, such a situation sets up a classic conflict between ethical action and the profit-maximizing interest of corporations. Recognizing that such conflicts do occur is important. Students can then be invited to consult their moral intuitions regarding how such a conflict should be resolved and potential sources of action justified, trotting out off-the-shelf moral theory as appropriate. However, the emphasis on the engineer's need for autonomy from business imperatives does not encourage the exploration of features of the engineer's own workplace practice that may contribute to such conflicts when they occur. Without focusing on engineering practice, engineering ethicists will promote crisis ethics rather than preventative ethics when considering the place of public safety among salaried engineers (Harris, Pritchard, and Rabins 1995, 14). For the ethicist or the practicing engineer, this situation allows one to valorize those individuals who resisted a course of action now identified retrospectively as leading to a disastrous outcome. Often this results in a fixation on the personal qualities of a whistle-blower (or "near whistle-blower" like Boisjoly) or on general "lessons" that can be abstracted from the particular case.

Engineering Culture and Ethical Reflection

Most engineers operate in an environment where their capacity to make decisions is constrained by the corporate or organizational culture in which they work. Engineers are rarely free to design technologies apart from cost and schedule pressures imposed by a corporate hierarchy, a government agency concerned with its image, or market pressures. Rules governing proprietary information and internal standards of secrecy and confidentiality make it difficult for everyone within an organization to have a clear appreciation of all the design concerns that may exist. Consequently, the emphasis on whistle-blowing by many engineering ethicists is certainly understandable; making information public, informing regulatory agencies, or circumventing corporate hierarchies may be the only options available to engineers who believe a serious threat to public health and safety exists that is being ignored by their employers. We certainly do not want to discourage whistle-blowing in such circumstances, nor are we comfortable with arguments against whistle-blowing that seek to defend the corporation's interests against employees adopting a concern with the public interest.

Engineers—even public-spirited, highly ethical engineers—do not spontaneously and infallibly know what the public interest demands or when they should intervene on its behalf. Vaughan's (1996) analysis helps us to see that the fixation on whistle-blowing results from an illusion of perspective. The ethicist is not immersed in the setting facing the engineer and can more easily imagine alternative scenarios or consider the trajectory of decisions made by an organization apart from the pressing need facing the engineer to meet his or her obligations moment to moment. We believe that it is possible to provide conceptual tools that might allow engineers to problematize aspects of their working culture by drawing on Vaughan's analysis of the normalization of deviance in the *Challenger* case.

Such an approach has two advantages over a focus on post hoc studies of disasters and idealized ethical dilemmas. First, engineering students are encouraged to attend to features of everyday engineering practice rather than just abstract moral theories or professional codes. While important, moral theories and professional codes may not have an obvious connection to engineering practice, even when rights and duties within organizations are considered. Without establishing strong links between the concepts used to discuss ethics in the classroom and aspects of the "real-world" settings that students will face, there is no reason to think that students will "activate" the knowledge they have learned in the classroom in their professional lives. Second, the features of ordinary engineering practice discussed are shown to have played a role in engineering disasters. Consequently, thinking about engineering disasters as growing out of mundane practice can allow students to draw connections between everyday work environments and detailed postmortems of engineering disasters.

Amoral Calculators, Whistle-Blowers, and the Micro-Macro Problem

Why does the "amoral calculator" provide such a convincing explanation to sociologists, engineers, and laypeople alike? The first thing to notice is that postulating the existence of amoral calculators allows one to solve what social theorists call the micro-macro problem (Alexander et al. 1987; Knorr-Cetina and Cicourel 1981). On one hand, we can see that decisions were made that appear in hindsight to be irrational: mounting evidence of problems with O-rings and deviation from initial design specs are ignored as time and time again the problems are referred to further study while launch go-aheads are given. On the other hand, we can see that institutional and political pressures to maintain schedule and to contain costs existed throughout this period. Therefore, it is concluded that production pressures and cost concerns must have supplanted known safety concerns: NASA management must have consciously chosen to risk disaster to satisfy such extra-technical pressures. When it comes to documenting this story, the Presidential Commission was able to identify apparent violations of established rules; the leap could easily be made to explaining such rule violations by rational choice calculations trading off safety for cost and schedule. The case can then serve as a lesson for students to avoid mere rational choice and employ an ethical perspective.

The only problem with this picture is that it is false. Vaughan (1996) provides us with a close examination of established procedures for monitoring and responding to design concerns, showing that apparent rule violations were in fact in conformity with the rules and that engineers were convinced that the O-ring problems, while real and requiring further study, were within their construction of acceptable risk. Vaughan mobilizes two kinds of arguments to establish the normality of decision making here. First, by drawing on a diachronic, incremental account of the evolving understanding of risk by the work group culture, she shows how technical deviance was normalized, leading to an honest identification of acceptable risk by engineers despite their awareness of mounting, serious problems. (Here the work group's self-understanding is reinforced by the cultures of production and secrecy.) Second, by drawing on work in the sociology of science and technology, she undermines the "obviousness" and self-certainty of retrospective judgments that the O-ring problems required suspension of shuttle flights until redesign was accomplished. Scientists and engineers work within a "sea of anomalies"; engineers designing novel, complex technical systems cannot always anticipate all problems and must adjust prior specifications in line with evolving experience. Moreover, engineering practice rightly regards frequent, radical changes in design as problematic since such changes are bound to introduce as-yet-unknown problems, substituting unknown and possibly severe problems for known and presumably manageable ones (Petroski 1985). Like scientists, engineers work within a framework that shapes the kind of anomalies one ought to expect and the kinds of responses that are likely to be successful. Finally, engineers are convinced of their ability to arrive at accurate knowledge of anomalous behavior; their commitment to the virtues of experimentation and quantification itself contributes to their confidence that design problems are not life threatening.

Rethinking Small Cases

Teachers in engineering ethics use both large and small case studies, the former for essays and research papers and the latter for treatment of a single issue in a class period. How can the small cases—hypothetical scenarios used to explore moral dilemmas—be reworked to provide a more realistic understanding of engineering practice? We suggest three approaches. First, hypothetical cases should be rewritten to reflect features of culturally embedded engineering practice. Second, written exercises should be used to encourage students' creativity, attention to detail, and the need for persuasion. Third, students should engage in role-playing exercises that allow them to explore the perspective of others.

For writing and role-playing exercises to be effective, it is imperative that hypothetical cases be rewritten to reflect the complex and open quality of engineering practice rather than the current emphasis on clearly framed conflicts of values.[22] Small cases can never be presented in full ethnographic detail by their nature. However, hypothetical cases can simulate the incremental and contextually embedded character of real-life ethical problems by providing (1) contextual background on the organizational setting and past design history of the case and (2) removing cues that frame the case as one clearly defined issue rather than another. By providing relatively "unedited" contextual background, the goal should be to provide sufficient resources for the student to creatively explore solutions rather than being forced to choose one horn of a dilemma (e.g., lose job or resist supervisor). Most teachers help students think about alternatives already; however, most cases are written to require a choice of only a few options.[23] By including a variety of tacit ethically salient details, the student can be asked to anticipate likely problems and possible solutions rather than merely uncovering the teacher's preferred right answer.

Students can be given writing assignments that ask them to respond creatively to hypothetical cases using the resources introduced by an examination of Vaughan's (1996) book or other work focusing on engineering practice. Consider, for example, the case of "Jay and the catalyst," a typical case limited by its focus on a moral dilemma divorced from contextual detail. As this case is presented, Jay is an engineer working for an acknowledged expert on catalysts who is convinced that catalyst A is superior to catalyst B, although the results of tests performed by inexperienced assistants suggest B is superior. Jay is ordered to work the math backwards to justify the consensus among Jay and the work group that A is superior despite the test results. The student is presented with a number of options from which to choose, including writing the report, refusing, writing the report along with a memo objecting to the unethical order, writing the report but refusing to sign, or complaining directly to the boss's supervisor. Not surprisingly, most students choose "other" and attempt to craft a better scenario making use of the few details available—for instance, suggesting that the tests be run again on the side, that reasons for preferring A be presented without working the math backwards, that the tests be reported but their accuracy questioned, or that Jay attempt to change the boss's mind.[24]

Teachers adopting a perspective rooted in moral theory may feel that these other options reflect the tendency of engineers to find some "technical" fix that avoids ethical dilemmas altogether. From our perspective, they represent serious efforts to find practical, ethically acceptable solutions that make use of features of the case as presented, efforts that would be encouraged by providing narrative background on established procedures, informal routines, organizational goals and history, and personalities. Without rigging the dilemma to highlight the problem of falsified data, the students could be presented with an ongoing decision stream with enough details to allow them to craft their own course of action instead of choosing from a list of options at one moment in time. Among the features of this case that students may wish to explore apart from the "amoral calculation" of falsifying data are the need for engineering judgment, the authority and fallibility of quantitative and experimental proof, the role of background assumptions in engineering decisions (requiring that some assumptions be presented in the case), the significance of precedents (what future consequences will there be for each course of action?), and the effect of production pressures and organizational secrecy. Finally, engineers can be asked to craft persuasive arguments for their course of action. Courses incorporating engineering ethics are ideal sites for incorporating "writing across the curriculum" in the engineering curriculum. Interactive approaches to writing emphasize the need for peer review and feedback; classroom role-playing can accomplish this goal while encouraging engineers to understand the perspectives of those in other positions.[25] For example, Jay's boss may experience production pressures in a less mediated fashion than Jay: how would this affect the way he would respond to the solutions arrived at by students? Each student could alternate playing Jay and playing his boss or other members of the team to more realistically simulate ethically loaded decisions in organizational settings.

Rethinking Large Cases

Vaughan's (1996) book should serve as a model for historical and ethnographic treatments of engineering practice that are sensitive to how judgments of acceptable risk are made in complex organizations. The "large cases" treating engineering disasters that serve as the other primary instructional resource in engineering ethics would benefit from treatment by researchers as sensitive as Vaughan. However, Vaughan's study can also be used as a paradigm case for comparing other engineering disasters, as well as to make clear which ordinary features of engineering practice can have ethical import. To rework existing material on large-scale engineering disasters, teachers should take a similar approach to that recommended for small cases. First, lecture and discussion should consider routine, mundane procedures and practices contributing to spectacular disasters rather than isolate potential moments of whistle-blowing. Second, students should engage in writing exercises that ask them to compare creatively other cases to features of the *Challenger* case, as well as to imagine how written persuasion might affect established procedures in a manner that corrects for the normalization of deviance. Third, students can engage in role-playing exercises in which even scapegoated "amoral" managers are forced to justify their actions to better appreciate the constraints in which they act and the possibilities for addressing them.

To see how a focus on the ongoing production of culture in ordinary engineering practice allows us to shed new light on canonical large cases in engineering ethics, we turn to a brief consideration of how the DC-10 case has been handled. In 1970, ground testing uncovered a design flaw linking the cargo doors, the passenger cabin floor, and the steering mechanism of the DC-10. When the forward cargo door blew open during a test, a partial collapse of the floor ensued. Damage to the floor threatened control systems running through the floor, potentially interfering with the pilot's ability to fly the plane. Although changes in the cargo door design were made, McDonnell Douglas and subcontractor Convair continued to debate whether further design changes were necessary and which party would be responsible for the costs of redesign. In June 1972, American Airlines Flight 96 out of Detroit managed to land safely in Windsor, Ontario, following loss of the rear cargo door, leading to partial floor collapse and damage to some control lines. The National Transportation Safety Board concluded that design changes to the cargo door were inadequate and that the Federal Aviation Administration (FAA) should not have approved a design in which loss of a cargo door could disable flight control. Internal to Convair, Director of Product Engineering Dan Applegate wrote a memo calling for Convair to convince McDonnell Douglas that a redesign was necessary, but his request was rejected by Program Manager J. B. Hurt and Vice President M. C. Curtis (Sawyier 1983; Fielder and Birsch 1992).

Meanwhile, the FAA had not issued a public airworthiness directive requiring specific changes to the DC-10 as a result of the Windsor incident. Rather, FAA head John Shaffer entered into an informal "gentleman's agreement" with Jackson McGowen, president of McDonnell Douglas's Douglas division, to notify airlines of necessary modifications. Compliance with McDonnell Douglas's service bulletins was slow. Moreover, a plane in the possession of McDonnell Douglas at the time of the service bulletins was left largely unmodified, with only the required addition of a viewing port for visual inspection of the lock pin completed, despite written documentation and certification stamps attesting that the changes had been made.

This plane was sold to Turkish Airlines (Turk Hava Yollari, THY), with instructions for proper closure of the rear cargo door written in English. On 3 March 1974, the cargo door on this plane blew out about ten minutes after takeoff from Paris. Unlike the flight out of Detroit in 1972, the plane was at full capacity, leading to greater damage to the floor and a subsequent loss of control. The plane crashed, killing all 346 people on board. With the station engineer in Istanbul on a training course and the replacement engineer apparently not involved in inspecting the cargo door, M. Mahmoudi, a baggage handler fluent in several languages—but not English—closed the door without inspecting the lock pin.

With the Applegate memo calling for redesign rejected by Convair management, the informal gentleman's agreement entered into by an FAA head eager to promote the airline industry, and apparent lying and improper practices at McDonnell Douglas and THY, this case offers plenty of grist for the engineering ethics mill. Yet if engineering students are to glean insights applicable in their working lives, teachers must do more than identify potential moments of whistle-blowing or externalize blame by condemning individuals, corporations, or regulatory agencies.[26] They must succeed in conveying meaningful connections between such disaster studies and aspects of ordinary engineering practice over which working engineers have some measure of influence. In other words, the instructor should seek to counter the urge to externalize blame and instead identify features "internal" to a broad view of engineering practice that contribute to engineering disasters. In many cases, engineers accept responsibility for "technical" factors, while institutional or "political" factors are seen as the province of others. Yet in practice, many working engineers are engaged in activities that exceed the narrowly technical: engineers help negotiate contracts, manage organizations, report to regulators, anticipate market forces and social responses, and adjust technical design factors in response to all of these (Latour 1996).

We suggest three areas of focus for building connections between the DC-10 case and ordinary engineering practice: contracting, regulation, and technology transfer. A key structural aspect of the situation that becomes apparent from the Applegate memo involves the relationship between Convair and Douglas. By contract, Convair was held responsible for design changes instituted after initial acceptance of the design philosophy, when the troubled latch mechanism was adopted rather than venting provisions to prevent floor collapse in the event of a cargo breach. This motivated Convair management to reject Applegate's recommendation that Convair push Douglas to incorporate floor venting provisions.[27] Here contractual and financial considerations affected design decisions. At the same time, engineers are frequently involved in negotiating such contracts and may have the opportunity to consider in advance how the contractual details may tie their hands.

Class discussion can simultaneously establish a possible connection between engineers' work, a "nontechnical" component of their industry, and an engineering disaster. More important, the class can examine a variety of ways in which contractual considerations may shape future engineering decisions and encourage students to consider such mundane elements as technically and ethically significant. Engineers in the private and public sectors can be brought in to class to discuss how contracting is done. Students can be assigned to research contracting procedures in a particular industry and to uncover or anticipate problems that may arise. With the DC-10 case to act as a paradigm case highlighting the significance of contracting, students can treat creatively other situations in which potential problems are less clear.

It is common to think of regulation as "external" to corporate decision making, yet regulators often rely on engineers employed by corporations. In the airline industry, most inspections are carried out by designated engineering representatives (DERs) employed by manufacturers but acting on behalf of the FAA (Fielder and Birsch 1992, 3). In the DC-10 case, the head of the FAA entered into an informal agreement with Douglas to fix the cargo door. While many have criticized the structural contradiction between the FAA's role as a regulatory agency and as a promoter of industry, it is also true that government regulators can rarely proceed in a completely independent fashion if they are to be effective.

Vaughan (1996) argues that safety oversight at NASA by both internal and external agencies relied on the "definition of the situation" provided by the Solid Rocket Booster (SRB) work group (p. 271). The effectiveness of regulators was limited simultaneously by the relative autonomy of regulators and organizations and by the necessary interdependence of the two. When autonomy dominates, regulators can maintain independence and an appropriately adversarial relationship but have limited access to information and resources for tracking problems. Greater interdependence brings significant improvements in monitoring safety at the cost of greater reliance on the resources, interests, and goals of the regulated organization (p. 264-66).

Students can be asked to find out how regulation actually takes place in a particular industry—as opposed to what regulations require formally. Who is responsible for inspections? Who employs them? How do the number of inspectors and the resources available to them compare with their responsibilities? To what extent do they rely on information provided by engineers working within organizations? How formal or informal is this relationship? Do safety procedures within the corporation take for granted the independence and effectiveness of regulatory procedures? As informed citizens, how should engineers speak out individually or collectively to reform regulatory agencies?

In the DC-10 case, crucial safety instructions were written in English despite the fact that planes were eventually sold overseas. Moreover, the gentleman's agreement called for design changes instituted by service bulletins to the airlines, including a peephole requiring proper inspection by an operator (Eddy, Potter, and Page 1992b, 116). Compliance with required design changes and operator training was slow for U.S. airlines at the time.[28] Given the informal nature of the changes instituted within the U.S. airline industry, compliance with required training procedures outside the United States was not ensured. McDonnell Douglas consistently used the existence of "improper maintenance procedures" to justify design safety following accidents.[29] Yet, the existence of service bulletins advising airlines of proper procedures does not ensure that changes will be instituted as envisioned, particularly when users of a technology operate in a different linguistic, cultural, and regulatory framework than the manufacturers. Typically, engineers focus on an immediate target user when designing a new technology while rarely considering which other users in different countries or cultural settings may eventually employ the technology. Students can be assigned to assess how particular technologies developed in one context are used in another, considering to what extent engineers can anticipate how the variety of users who may adopt a technology should shape design and safety assumptions.

For each element of "nontechnical" practice—contracting, regulation, and technology transfer—if engineers can learn to anticipate possible ways in which the "normalization of deviance" may occur, the incremental degradation of safety standards may be reversed in some cases. In each case, educators can help students to balance critical reflection with a perspective rooted in mundane engineering practice. Like regulators balancing autonomy and interdependence, engineering ethics instructors must help students to recognize how problematic decisions seemed rational at the time, avoiding the vice of selective hindsight while still providing conceptual tools for thinking about how elements of ordinary engineering practice can lead to or counter the normalization of deviance, providing for a critical perspective on engineering in organizations. The field of science and technology studies is well placed to develop research and teaching to fulfill this goal.

Notes

1. Martin and Schinzinger (1996, 35) define moral autonomy as "the ability to arrive at reasoned moral views based on the responsiveness to humane values most of us were taught as

children." For Martin and Schinzinger, moral autonomy does not ensure that a single, correct decision will be made but rather that moral problems can be recognized, clarified through reasoning, and communicated about with an understanding that others may come to different conclusions. Vesilind (1988, 292-93) similarly emphasizes that morals cannot be taught but that "methods of making personal decisions" can.

2. Jonsen and Toulmin (1988); Arras (1991). For a textbook drawing heavily on casuistry, see Harris, Pritchard, and Rabins (1995, chap. 5).

3. See Harris, Pritchard, and Rabins (1995, 14): "Practice in preventative ethics involves stimulating the moral imagination, developing analytical skills in dealing with ethical problems, eliciting in engineers a sense of responsibility for their actions, and helping engineers to tolerate and also to resist disagreement and ambiguity." On finding a creative middle way, see page 13, chapters 4 through 6. See also Martin and Schinzinger (1996, chap. 3).

4. Harris, Pritchard, and Rabins (1995, 278) seek to avoid amoral calculation by delineating the proper responsibilities of both engineers and managers.

5. See the Online Ethics Center for Engineering and Science's (1999) section on positive role models, which includes Boisjoly and Carson, along with William LeMessurier. The emphasis on positive role models rightly counters the disabling emphasis by ethicists on everything that engineers have done wrong, and it potentially points future engineers in the direction of constructive actions they could take in remedying ethical problems in the workplace.

6. For an account of the precarious legal position of whistle-blowers, see Malin (1983).

7. MIT's Mechanical Engineering Department began to require students in its design projects course in 1987 to contact companies to determine what resources they offered to help employees facing ethical issues (Whitbeck, 1987). For a survey of existing approaches to teaching engineering ethics, see Lynch (1997-1998).

8. Some philosophers of science have begun to challenge their discipline's history of evaluating science without regard to its socially situated character, drawing on approaches to studying science from sociology, cultural studies, and history. See Fuller (1988) and the journal *Social Epistemology*; Rouse (1996); Galison and Stump (1996).

9. Michael Davis (1998, 69-70) had already argued that the launch decision should be viewed as a "normal process" or "social process." Lund's decision to accept the launch was not "careless, ignorant, incompetent, evil-willed, weak-willed, morally immature, or self-deceiving" (p. 68). Vaughan's (1996) analysis differs from Davis's by rejecting an analysis based on a conflict of roles between managers and engineers, substituting a detailed historical ethnography of the engineers' own construction of risk through the past history of their engineering practice.

10. For Vaughan (1996), as for Clarke (1992), scapegoating individuals blocks consideration of the structural causes of engineering disasters.

11. Vaughan (1996, 355): "Thus, when Marshall challenged Thiokol to 'prove it' by 'quantifying their concerns,' they were asking Thiokol to conform to the standards of the original technical culture by supplying quantitative data. When Boisjoly replied, 'I couldn't quantify it. I had no data to quantify it, but I did say I knew it was away from goodness in the current data base,' his reference to 'away from goodness in the current data base' was known in NASA culture as 'an emotional argument.' 'Real' technology conformed to the norms of quantitative, scientific positivism. Any Flight Readiness Review [FRR] engineering analysis that did not meet these standards was, in effect, a weak signal in the NASA system." Postaccident temperature analysis compared data from both flights with and without field joint problems, revealing a clear demonstration that cold had a negative effect—all flights below 63 degrees Fahrenheit had O-ring problems. At the time, engineers only considered flights with problems that revealed no correlation between temperature and O-ring damage. Vaughan (1996, 382-85) explains this decision as rooted in the assumptions about the known effects of cold based on the prior flight

history, while Pinkus et al. (1997, 318-19) consider this the result of the failure to educate engineers on proper quantitative trend analysis. Jasanoff (1991) compares British and U.S. regulatory strategies for responding to the risks of lead in gasoline, finding that the United States was committed to finding quantitative proof before remedial action could commence, while Britain sought to make the best scientific judgment whether or not epidemiological proof of harm was forthcoming. An assessment of the relative strengths of quantitative and qualitative risk analysis can be found in Jasanoff (1993).

12. On Mason's decision to make a management decision, Vaughan (1996, 317) quotes Thiokol's Joe Kilminster: "There was a perceived difference of opinion among the engineering people in the room, and when you have differences of opinion and you are asked for a single engineering opinion, then someone has to collect that information from both sides and make a judgment." Here a management opinion is not opposed to engineering opinion but is a (single) engineering opinion, relying on a judgment drawing on information presented by both sides. The key structural problem may be that engineers were not encouraged to exercise professional judgment when quantitative proof was lacking; only managers in situations of dissensus were so authorized. Harris, Pritchard, and Rabins (1995, 284) interpret Mason's claim that a judgment was necessary given the lack of quantitative data in terms of a possible argument for why the decision was a proper management decision (PMD) but question whether such an argument would succeed. They argue that "the decision to launch violated engineers' propensity to modify or change course only in small increments" (p. 285).

13. Lund recalls that Mason "wasn't asking me to do something dumb. You know, of all things he didn't want to do was fly the Challenger and have—you know, that would be dumb. There is no question about that. And so he was asking for a judgment, you know, he was asking for the judgment that I could best make, and I tried to provide that judgment to him" (Vaughan 1996, 319).

14. Vaughan (1996, 390) does question the decision by NASA administrators to promote the shuttle as a routine rather than developmental technology, while Pinkus et al. (1997, chap. 5) suggest that the decision to build the shuttle for about half the original proposed cost contributed to the disaster.

15. Harris (1995, 26) suggests that if NASA and Thiokol "had established a more open and non-intimidating atmosphere for their engineers and had been more adept at listening to the engineers' concerns," disaster may have been avoided, but he does not suggest what kinds of institutional changes will bring about this state of affairs. For an analysis of the management structure and culture, see Werhane (1991).

16. Harris, Pritchard, and Rabins (1995, 278) are an exception in this respect since they spell out rules for professional ethics and responsibility for managers as well, although conflict between engineers and managers over public health and safety is still the primary focus of concern.

17. Unger (1994, 3, 15-16); Nader (1983, 280): see also the variety of views on this issue in section 5 of this collection.

18. Porter (1995); Wynne (1988); Law (1987); Vincenti (1990); Meiksins and Watson (1989). For a discussion of technology as a distinct form of knowledge and activity, see Mitcham (1994, chaps. 8-9).

19. See, for example, the case of an engineer responsible for safety, Brenda, directed by her supervisor not to study an accident that would normally fall under her jurisdiction or the dilemma faced by Ed, who is told by his boss not to report a cyanide dump in Perry (1981) and Kohn and Hughson (1980). For a variety of cases, see the Online Ethics Center for Engineering and Science (1999).

20. Whitbeck (1995, 1997). Harris, Pritchard, and Rabins (1995, 136) urge students to seek a "creative middle way" when faced with conflicting ethical demands.

21. Rather than encouraging students to identify problems on their own, current engineering education predefines problems for students and provides carefully scripted techniques for finding answers (Downey 1998a, 1998b, 139-41).

22. For cases along the lines we have recommended here, see the Engineering Ethics (2000) home page from the University of Virginia.

23. See Harris, Pritchard, and Rabin (1995, 136-40) for a discussion of finding a "creative middle way."

24. Kohn and Hughson (1980). This small case is notable for including a follow-up exercise in which it turns out that catalyst B is superior. See Harris, Pritchard, and Rabins (1995, 82) for a suggestion of a "creative middle way" for this case.

25. For an argument that role-playing can promote ethical reasoning, see Lickona (1980, 114).

26. Drawing on Vaughan's (1996) analysis is helpful here. What is it about the conditions leading up to Applegate's strong memo of 27 June 1972 that made this too weak a signal to counteract acceptance of the design? Kipnis (1992, 153) subjects this memo to scrutiny to justify his own preferred criteria for why Applegate should not have continued to participate in a project he "was almost certainly aware . . . would inevitably kill people, people who were not aware, who could not be aware, of the risks to which they were subject." Eddy, Potter, and Page (1992a, 108) likewise conclude that "the dangers were, or *should have been*, obvious" to Douglas and Convair (emphasis added). The qualifications are significant here: Applegate "almost certainly" knew; the companies "should have been" aware of the dangers. Analysis of this kind depends on putting oneself in Applegate's place, considering the information available to him at the time, and judging whether signals of danger should prompt one to action. What this exercise misses is the effect on one's judgment of options that the stream of past decisions may have had on the urgency of action at that particular moment and the perceived sufficiency of his actions to meeting the danger. When cases such as this one are presented to students, they tend to follow the analysts of whistle-blowing in imaginatively projecting oneself into the potential whistle-blower's place and considering what actions they would take without attending to the contextual embeddedness of this event in an ongoing decision stream and the ethically salient aspects of the process that could fruitfully be attended to at earlier stages.

27. Eddy, Potter, and Page (1992a, 106-7). Like the *Challenger* case, the design and redesign of the DC-10's latch would seem to involve the normalization of deviance. Compare the Applegate memo to W. Leon Ray's memos, discussed in Vaughan (1996, 100-101). Vaughan also discusses the role of memos containing "bad news" in the normalization of deviance; Ray was known for writing such memos (p. 113).

28. See the memorandum from the House of Representatives, Special Subcommittee on Investigations, Committee on Interstate and Foreign Commerce, reprinted in Fielder and Birsch (1992, 124-25).

29. See Brizendine (1992, 200) regarding another DC-10 accident in Chicago, 1979, and McDonnell Douglas (1992, 229).

References

Alexander, Jeffrey C., Bernhard Giesen, Richard Munch, and Neil J. Smelser, eds. 1987. *The micro-macro link*. Berkeley: University of California Press.

Alpern, Kenneth D. 1983. Engineers as moral heroes. In *Beyond whistleblowing: Defining engineers' responsibilities: Proceedings of the Second National Conference on Ethics in*

Engineering, March 1982, edited by V. Weil, 40-55. Chicago: Center for the Study of Ethics in the Professions, Illinois Institute of Technology.

Arras, John D. 1991. Getting down to cases: The revival of casuistry in bioethics. *Journal of Medicine and Philosophy* 16:29-51.

Bell, Trudy E., and Karl Esch. 1987. The fatal flaw in flight 51-L. *IEEE Spectrum*, February, 36-51.

Boland, Richard J. 1983. Organizational control systems and the engineer: The need for organizational power. In *Beyond whistleblowing: Defining engineers' responsibilities: Proceedings of the Second National Conference on Ethics in Engineering, March 1982*, edited by V. Weil, 200-210. Chicago: Center for the Study of Ethics in the Professions, Illinois Institute of Technology.

Brizendine, John C. 1992. Statement of John C. Brizendine, president, Douglas Aircraft Company, McDonnell Douglas Corporation. In *The DC-10 case: A study in applied ethics, technology, and society*, edited by John H. Fielder and Douglas Birsch, 199-203. Albany: State University of New York Press.

Clarke, Lee. 1992. The wreck of the *Exxon Valdez*. In *Controversy: Politics of technical decisions*, edited by Dorothy Nelkin, 80-96. 3d ed. Newbury Park, CA: Sage.

Collins, H. M. 1985. *Changing order: Replication and induction in scientific practice*. London: Sage.

Davis, Michael. 1991. Thinking like an engineer: The place of a code of ethics in the practice of a profession. *Philosophy & Public Affairs* 20:150-67.

———. 1998. *Thinking like an engineer: Studies in the history of a profession*. New York: Oxford University Press.

Downey, Gary Lee. 1998a. Ethics and engineering selfhood. Paper presented at the Society for Social Studies of Science Annual Conference, October, Halifax, Canada.

———. 1998b. *The machine in me: An anthropologist sits among computer engineers*. New York: Routledge Kegan Paul.

Downey, Gary Lee, and Juan C. Lucena. 1995. Engineering Studies. In *Handbook of science and technology studies*, edited by Sheila Jasanoff, Gerry Markle, James Petersen, and Trevor Pinch, 167-88. London: Sage.

Eddy, Paul, Elaine Potter, and Bruce Page. 1992a. The Applegate memorandum. In *The DC-10 case: A study in applied ethics, technology, and society*, edited by John H. Fielder and Douglas Birsch, 101-8. Albany: State University of New York Press.

———. 1992b. Fat, dumb, and happy: The failure of the FAA. In *The DC-10 case: A study in applied ethics, technology, and society*, edited by John H. Fielder and Douglas Birsch, 109-22. Albany: State University of New York Press.

Engineering Ethics. 2000. Home page, Division of Technology, Culture, and Communication, University of Virginia [Online]. Available: http://repo-nt.tcc.virginia.edu/ethics/

Fielder, John H., and Douglas Birsch, eds. 1992. *The DC-10 case: A study in applied ethics, technology, and society*. Albany: State University of New York Press.

Florman, Samuel C. 1983. Comments on Pletta and Gray and Schinzinger. In *Beyond whistleblowing: Defining engineers' responsibilities: Proceedings of the Second National Conference on Ethics in Engineering, March 1982*, edited by V. Weil, 83-89. Chicago: Center for the Study of Ethics in the Professions, Illinois Institute of Technology.

Fuller, Steve. 1988. *Social epistemology*. Bloomington: Indiana University Press.

Galison, Peter, and David J. Stump, eds. 1996. *The disunity of science: Boundaries, contexts, and power*. Stanford, CA: Stanford University Press.

Harris, Charles E., Jr. 1995. Explaining disasters: The case for preventative ethics. *IEEE Technology and Society Magazine* 14 (2): 22-27.

Harris, Charles E., Jr., Michael S. Pritchard, and Michael Rabins. 1995. *Engineering ethics: Concepts and cases*. Belmont, CA: Wadsworth.

Jasanoff, Sheila. 1991. Acceptable evidence in a pluralistic society. In *Acceptable evidence: Science and values in risk management*, edited by Deborah G. Mayo and Rachelle D. Hollander, 29-47. New York: Oxford University Press.

———. 1993. Bridging the two cultures of risk analysis. *Risk Analysis* 13:123-29.

Jasanoff, Sheila, Gerry Markle, James Petersen, and Trevor Pinch, eds. 1995. *Handbook of science and technology studies*. London: Sage.

Jonsen, Albert R., and Stephen Toulmin. 1988. *The abuse of casuistry.* Berkeley: University of California Press.

Kipnis, Kenneth. 1992. Engineers who kill: Professional ethics and the paramountcy of public safety. In *The DC-10 case: A study in applied ethics, technology, and society,* edited by John H. Fielder and Douglas Birsch, 143-60. Albany: State University of New York Press.

Knorr-Cetina, K., and A. V. Cicourel, eds. 1981. *Advances in social theory and methodology: Toward an integration of micro- and macro-sociologies*. New York: Routledge Kegan Paul.

Kohn, P., and R. Hughson. 1980. Perplexing problems in engineering ethics. *Chemical Engineering,* 5 May, 100-107.

Latour, Bruno. 1996. *Aramis or the love of technology.* Cambridge, MA: Harvard University Press.

Law, John. 1987. On the social explanation of technical change: The case of the Portuguese maritime expansion. *Technology and Culture* 28:227-52.

Lickona, Thomas. 1980. What does moral psychology have to say to the teacher of ethics? In *Ethics teaching in higher education,* edited by Daniel Callahan and Sissela Bok, 103-32. New York: Plenum.

Lynch, William T. 1994. Ideology and the sociology of scientific knowledge. *Social Studies of Science* 24:197-227.

———. 1997-1998. Teaching engineering ethics in the United States. *IEEE Technology and Society Magazine* 16 (4): 27-36.

Malin, Martin. 1983. Legal protection for whistleblowers. In *Beyond whistleblowing: Defining engineers' responsibilities: Proceedings of the Second National Conference on Ethics in Engineering, March 1982,* edited by V. Weil, 11-32. Chicago: Center for the Study of Ethics in the Professions, Illinois Institute of Technology.

Mark, Hans. 1987. *The space station: A personal journey.* Durham, NC: Duke University Press.

Martin, Mike W., and Roland Schinzinger. 1996. *Ethics in engineering.* 3d ed. New York: McGraw-Hill.

McDonnell Douglas. 1992. The DC-10: A special report. In *The DC-10 case: A study in applied ethics, technology, and society,* edited by John H. Fielder and Douglas Birsch, 227-35. Albany: State University of New York Press.

Meiskus, Peter, and James Watson. 1989. Professional autonomy and organizational constraint: The case of engineers. *Sociological Quarterly* 30:561-85.

Merton, Robert K. 1979. The normative structure of science. In *The sociology of science: Theoretical and empirical investigations*, edited by R. K. Merton. Chicago: University of Chicago Press.

Mitcham, Carl. 1994. *Thinking through technology: The path between engineering and philosophy.* Chicago: University of Chicago Press.

Nader, Ralph. 1983. The engineer's professional role: Universities, corporations, and professional societies. In *Engineering professionalism and ethics*, edited by James H. Schaub and Karl Povlovic, 276-84. New York: John Wiley.

Online Ethics Center for Engineering and Science. 1999. [Online]. Available: http://onlineethics.org

Perry, T. 1981. Five ethical dilemmas. *IEEE Spectrum*, June, 53-60.

Petroski, Henry. 1985. *To engineer is human: The role of failure in successful design*. New York: St. Martin's.

Pinkus, Lynn B., Larry J. Shuman, Norman P. Hummon, and Harvey Wolfe. 1997. *Engineering ethics: Balancing cost, schedule, and risk—Lessons learned from the space shuttle*. Cambridge, UK: Cambridge University Press.

Porter, Theodore M. 1995. *Trust in numbers: The pursuit of objectivity in science and public life*. Princeton, NJ: Princeton University Press.

Rouse, Joseph. 1996. *Engaging science: How to understand its practices philosophically.* Ithaca, NY: Cornell University Press.

Sawyier, Fay. 1983. The case of the DC-10 and discussion. In *Engineering professionalism and ethics*, edited by James H. Schaub and Karl Pavlovic, 388-401. New York: John Wiley.

Unger, Stephen H. 1994. *Controlling technology: Ethics and the responsible engineer.* 2d ed. New York: John Wiley.

Vaughan, Diane. 1996. *The Challenger launch decision: Risky technology, culture, and deviance at NASA*. Chicago: University of Chicago Press.

Vesilind, P. Aarne. 1988. Rules, ethics and morals in engineering education. *Engineering Education*, February, 289-93.

Vincenti, Walter. 1990. *What engineers know and how they know it*. Baltimore: Johns Hopkins University Press.

Weil, Vivian, ed. 1983. *Beyond whistleblowing: Defining engineers' responsibilities: Proceedings of the Second National Conference on Ethics in Engineering, March 1982*. Chicago: Center for the Study of Ethics in the Professions, Illinois Institute of Technology.

Werhane, Patricia H. 1991. Engineers and management: The challenge of the *Challenger* incident. *Journal of Business Ethics* 10:605-16.

———. 1987. Integrating ethics teaching into courses in engineering design. *Science, Technology & Society* 62/63:12-17.

Whitbeck, Caroline. 1987. Experience with the project method of teaching ethics in a class of engineering design. Unpublished manuscript.

———. 1995. Teaching ethics to scientists and engineers: Moral agents and moral problems. *Science and Engineering Ethics* 1:299-308.

———. 1997. Using problems and cases in teaching professional ethics: Theory and practice. In *Teaching criminal justice ethics: Strategic issues*, edited by John Kleinig and Margaret L. Smith. Cincinnati, OH: Anderson.

Wynne, Brian. 1988. Unruly technology: Practical rules, impractical discourses and public understanding. *Social Studies of Science* 18:147-67.

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