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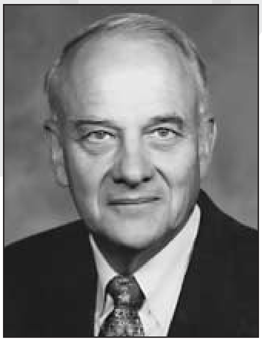
Editorial



Wm. A. Wulf is president of the National Academy of Engineering.

Engineering Ethics

At the Annual Meeting of the National Academy of Engineering (NAE), the president is expected to present a brief lecture on a relevant engineering issue. For the 2000 meeting, I thought it would be appropriate for me to talk about the achievements of engineers in the twentieth century and the challenges facing them in the twenty-first century. My preparation of the first part of the lecture was made easier because we had already worked with the engineering professional societies to create a list of the 20 greatest achievements of the twentieth century—we selected the "greatest achievements" for their impact on people's lives, rather than for their technological "gee whiz." (You can see the list by following the obvious links from our home website, <*www.nae.edu*>.)

Preparing the second half of the lecture was harder, at least at first. As Neils Bohr once quipped, making predictions is difficult, especially predictions that look far into the future. Conventional wisdom about the near-term future of technology suggests that we have a wealth of technical opportunities and challenges. But my crystal ball is no better than anyone else's, and it becomes completely fogged up after a dozen years or so. How could I anticipate the challenges for a full century?

When I looked again at the list of the twentieth-century achievements, I was struck by two things. First, I was awed by how much engineers *matter*. Arguably, engineers and their creations did more to shape our lives than anything or anyone else in the last century! Second, I realized that the immense social impact of most of our inventions was not predicted by their inventors. As Norm Augustine says a bit later in this volume: "The bottom line is that the things engineers do have *consequences*, both positive and negative, sometimes unintended, often widespread, and occasionally irreversible."

Because of the enormous impact of engineers on individuals and society, we also have deep moral and ethical responsibilities. That realization changed the nature of my quest, and I began to read broadly and deeply about engineering ethics and its cousin, "applied ethics." In the end, I decided I would pose only one challenge for the twenty-first century—engineering ethics. The combination of the quickening pace of technological innovation, the widespread use of nano-, bio-, and information technology, and the increasingly complex systems we engineer is raising ethical questions that engineers in the twentieth century did not face. These issues go beyond the appropriate behavior of individual engineers to the appropriate behavior of the engineering profession.

Beyond making a speech about this at the Annual Meeting (although I *do* speak about it often), I became convinced that NAE is the one, pan-engineering organization that could lead the discussion on engineering ethics in the twenty-first century, with a strong emphasis on the new issues. My idea was enthusiastically backed by the NAE Council, and I asked Norm Augustine to chair a committee to suggest how we might best carry it out. The committee, which brought together engineers, ethicists, judges, lawyers, educators, and people from the private sector, is about to submit its report to me. Although I have an inkling of what it will say (and you may too after reading his article), I will defer discussing it until I've actually received it.

In closing, let me be clear. I believe that the vast majority of engineers behave ethically, and I do not think we are facing a crisis of moral decline. I am proud to be an engineer, in part at least because of the ethics of the profession. But as we move ahead and continue to touch the public in new ways, we need to think ahead about how our actions might affect people for good or ill. We must be prepared to practice in an ethical way as the circumstances change.

I am deeply grateful to the five authors who prepared articles for this issue of *The Bridge*. From time to time, we will certainly have other articles on the subject, especially as we implement the recommendations of Norm Augustine's committee.

Wm. A. Wulf

Engineers who make bad decisions often don't realize they are confronting ethical issues.

Ethics and the Second Law of Thermodynamics

Norman R. Augustine is a former chairman of Lockheed Martin Corporation, a former Under Secretary of the Army, and a former lecturer with the rank of professor at Princeton University. He has served on the board of the Ethics Resource Center and has been a trustee of Johns Hopkins and Princeton universities and MIT. He is a former chairman of NAE and chair of the NAE Committee on Engineering Ethics and Society.

Norman R. Augustine

During the years I had the privilege of teaching in the engineering school at Princeton, I began the first class session of every semester by announcing that a gentleman had invented a new product that virtually everyone in the world would want to have—a product that would create millions of new jobs and would greatly improve the quality of most people's lives. Furthermore, as luck would have it, he was seeking investors. When asked, most students expressed significant interest in investing in his endeavor (at least hypothetically—after all, they were students!). But when I added, "Oh yes, there is one other thing—his invention will kill a quarter of a million people each year" and asked if they would still be interested in investing, no one showed any interest in such a reprehensible product. Furthermore, most said that any such product should be banned outright. I then told them that the inventor's name was Nicholas Joseph Cugnot—and his invention was the automobile.

Imagine that you were responsible for the structural design of a building in Manhattan, the world's seventh tallest building, and that after the edifice was completed and fully occupied by its owners you, *and you alone,* discovered that there was an error in the design that could result in the structure's collapse in a type of storm that might be expected to occur every 16 years. What should you do? In this case, the "you" is Bill LeMessurier, a highly regarded structural engineer. He immediately informed the owner of the building and the authorities of the danger.

Or suppose you are a young, up-and-coming manager in a large corporation and that one day the chairman of the firm indicates to you that he is impressed with your work and is going to propose that you be elected to the board of directors. He goes on to say that there will be one condition: "You will always vote," he says, "exactly as I tell you." What should you do? In this case, the "you" is Herb Krannert—and his answer was simple. "I quit," he said. The following day six of his colleagues showed up at his front door saying they heard what happened and they too had quit—and they wanted to go to work for *him*! Together, they formed the Inland Container Corporation.

Or suppose you are an engineer responsible for overseeing the research and development work of an aerospace corporation by which you are employed; the company is doing some very early research on stealth technology, in which it is investing significant sums of money. Independently, you are asked by the government to serve, in a personal capacity, as chairman of an outside advisory board. In carrying out your duties for the government, you become aware that the government is funding research on stealth technology at another company based on an altogether different technical approach that is far more advanced than the work being done by your own company. How do you carry out your responsibilities to your company—and yet honor your duty of privacy to your client, the U.S. government, and, indirectly, to its contractor on the project? In this case, I was "the engineer."

These three examples span the spectrum of ethics from macroethics to microethics, and all of them involve engineering. Macroethics involves ethical issues that affect large segments of society, whereas microethics involves issues that affect a smaller, more immediate group, such as one's boss or one's client.

When raising the subject of ethics among engineers, their response is often, "What does ethics have to do with engineering? Engineering deals with equations and the principles of nature. The second law of thermodynamics is the second law of thermodynamics—no interpretation required." In fact, that certainty is precisely what attracted many of us to engineering in the first place.

But it's not that simple. As the examples suggest, engineering has a *great deal* to do with ethics; and most of the engineers whom I have seen get into trouble on ethical matters did so not because they were not decent people but because they failed to recognize that they were confronting an ethical issue. As a result, they made horrendously bad decisions—decisions they had to live with for the rest of their lives.

The oldest statement of ethics for the engineering profession is considered by many to be Cicero's Creed, which counsels that public safety must be preeminent in everything engineers do. By that standard, it is instructive to ask how well the engineering profession has performed. In examining such an emotion-laden issue, it sometimes helps to look at performance in the distant past. Hence, consider the designers of the *Titanic*, who provided 1,178 lifeboat positions on a ship that carried 2,224 passengers and crew. When disaster struck, 1,515 people lost their lives, at least in part because of this single decision. Was this a case of bad ethics or bad design—or both? If the engineers truly believed that the ship was unsinkable, then perhaps there was no need for any lifeboat places at all. If the ship was in fact sinkable, then there would presumably be a need for at least one lifeboat position for every person on board. In *no* case does providing lifeboat places for *half* the ship's occupants make any sense. Was it expected that the ship would *"half sink"*?

Certainty is what attracts many engineers to the profession, but things are not that simple.

Or consider the magnificent Crystal Palace designed by Sir Joseph Paxton for the Great Exhibition of 1851 in London as the centerpiece of that extravaganza. A contemporary news account described the testing procedures used to verify the design of the walkways in the imaginative structure:

> *The first experiment was that of placing a dead load of about 42,000 pounds . . . consisting of 300 of the workmen of the contractors, on the floors and the adjoining approaches . . . The fourth experiment—and that which may be considered the most severe test . . . was that of packing closely that same load of men, and causing them to jump up and down together for some time.*

Was this simply a convenient and inexpensive way to conduct a test, or was it an imaginative motivational technique, or was it a reflection of an ethical shortcoming?

How would the engineering practices for the *Titanic* and the Crystal Palace comport with Cicero's principle, and would practices such as these be condoned today? The bottom line is that the things engineers do have *consequences,* both positive and negative, sometimes unintended, often widespread, and occasionally irreversible. In fact, the ethical content of the decisions confronting engineers is increasing as the impact of their work reaches more and more people around the world. Consider questions such as whether oil fields should be established on the North Slope of Alaska; whether a renewed effort should be undertaken to build nuclear power plants; whether a dam should be built that would help prevent flooding but would severely impact the environment in the vicinity of the dam itself; whether new robots should be built that would increase efficiency but put large numbers of people out of work. Increasingly, engineers are realizing that simply because they *can* do something, does not necessarily imply that they *should* do it. A recent poll by Georgia Tech showed that 80 percent of the respondents believe that the *public* should have a say in the regulation of new technological innovations.

Nowhere is the complexity of these issues more challenging than in the burgeoning areas of genetics and so-called genetic engineering, which raises profound issues, such as whether cloning should be permitted, what sort of stem cell research is appropriate, and so forth. In the years ahead it is likely that engineers will become increasingly prominent in the biological sciences, adding another dimension to the decisions they face.

Simply because something can be done does not necessarily imply that it should be done.

Unfortunately, one can build a reasonable argument that modern terrorism has been made possible by advancements in science and technology. For the first time in history, individuals or very small groups of individuals—who can thus "live among us" in our free society—have leverage whereby they can profoundly and adversely impact the lives of very large groups. This has been brought about through the unintended consequences of past scientific and technological advancements.

Interestingly, engineers as a group enjoy a relatively good reputation in terms of ethical comportment. In Gallup polls conducted every year since 1976, engineers generally rank in the upper third (nurses are usually at the top, and car salesmen are usually at the bottom) in terms of confidence in their honesty and the ethics of their field. Another encouraging trend is that the absolute fraction of the public expressing confidence in the engineering profession has steadily increased over the years from about 45 percent to 60 percent in the most recent survey. This may, of course, be fortuitous because few engineering schools in America teach ethics, *per se*. In fact, some 80 percent of current engineering graduates are not required to take ethics-related courses at all. This may change, however, since the Accreditation Board for Engineering and Technology recently established a requirement that all engineering graduates be exposed to a formal ethics course. The teachings of Plato, Mill, Kant, Spinoza, Descartes, Nietzsche, Epicurus, Confucius, and others will indeed provide a very solid foundation for the understanding of ethics. But it is important that ethics courses also deal with the pragmatic issues that confront engineers in the rough-and-tumble, everyday world in which they live and work.

A reasonable question is why ethical issues require special courses in an already badly overburdened engineering curriculum. The answer is that, first, it is not always easy to recognize that an issue or decision has ethical connotations. Second, even then, it is often difficult to determine the ethical thing to do. Third, even when this has been determined, acting ethically often requires superhuman fortitude. And, finally, doing the ethical thing often does not lead to the desired outcome, at least not in the short term.

The problem is not so much associated with the Ivan Boesky school of ethics—Boesky once told students at UCLA that "greed is good"—as it is with the Charlie Brown school of ethics. For example, one day the peripatetic Charlie Brown's friend Lucy observes him shooting an arrow at a fence and then drawing a target around the spot where the arrow landed—with the point smack in the bulls-eye! Needless to say, Lucy becomes hysterical over Charlie's behavior—and her frame of mind is not helped when Charlie calmly explains, "But if you do it my way, you never miss."

Supreme Court Justice Potter Stewart once defined ethics as "knowing the difference between what you have a right to do and what is the right thing to do." One of the nation's great engineers, Glenn Martin, speaking of his friend Orville Wright, pointed out the advantages of ethical behavior in the field of engineering

> *I am convinced that it was his [Orville Wright's] devotion to the truth—in all things—that lay at the root of the Wright Brothers' success in creating the airplane . . . The quality of honesty in daily dealings is an infallible guide to a (person's) capabilities in the engineering and scientific fields. Structures and machines are unforgiving of the cheater and inevitably indict those who toy with the facts.*

One of the great attributes of our profession is that our work is judged by Mother Nature, an unfailingly consistent and fair judge—albeit a judge unforgiving of human error. But the work of engineers must do far more than comply with the laws of nature; it must also comply with the laws of society and must serve our principal client, humankind.

In this context, about a year ago—well before Enron, Rite Aid, Waste Management, Sunbeam, WorldCom, ImClone, Xerox, Tyco, Adelphia, Global Crossing, Computer Associates, Cendant, MicroStrategy, and others became front-page news—NAE President Bill Wulf established an NAE committee to determine if our Academy might play a role in ensuring that our profession and its members never face the derision now being heaped—broadly and often indiscriminately—on American business. The committee, which is comprised of engineers, lawyers, judges, ethicists, scientists, educators, industrialists, and others, will make its final report in the next few months. The committee is addressing both microethical and macroethical issues, but its emphasis is on the latter because many excellent forums are already addressing the former. Among the proposals being considered by the committee is the establishment within the NAE of a center for engineering ethics and society, the purpose of which would be to lay the groundwork for assisting engineers and the public in making difficult ethical decisions that impact large segments of society.

> *Mother Nature is a consistent and fair judge of human achievements—but she is unforgiving of human error.*

Warren Buffett once gave his son some good advice that also applies to engineering: "It takes years to build a reputation—and five minutes to ruin it. If you think about that, you'll do things differently." Although we can take pride in so much of what engineers have done over the years, we might wish to do a few things differently in the future.

The author discusses the pros and cons of pedagogical trends and curriculum models for teaching engineering ethics.

Continuing and Emerging Issues in Engineering Ethics Education

Joseph R. Herkert

Joseph R. Herkert is associate professor of multidisciplinary studies and director of the Benjamin Franklin Scholars Program at North Carolina State University.

In the past two decades, many changes have been made in engineering education, including a growing awareness of the importance of ethics and social responsibility to engineering. Prompted in part by political controversy over the social implications of technology and the changing educational standards promoted by the Accreditation Board for Engineering and Technology (ABET), engineering educators have begun to take seriously the challenge of preparing professionals who are both technically competent and ethically sensitive.

This is not to say that required courses in engineering ethics have become the norm. Stephan (1999) determined that nearly 70 percent of ABET-accredited institutions have no ethics-related course requirement for all engineering students. Although 17 percent of institutions do have one or more required courses with ethics-related content, these courses are not usually on engineering ethics per se, but on philosophy or religion or other subjects. Nevertheless, engineering ethics has begun to make its mark in engineering curricula as evidenced by required courses at some institutions, across-the-curriculum ethics initiatives, and numerous elective courses.

Content of Engineering Ethics Instruction

Davis (1999b) succinctly describes the hoped-for learning outcomes of teaching engineering ethics:

Teaching engineering ethics . . . can achieve at least four desirable outcomes: a) increased ethical sensitivity; b) increased knowledge of relevant standards of conduct; c) improved ethical judgment; and d) improved ethical will-power (that is, a greater ability to act ethically when one wants to).

A key concept in engineering ethics is "professional responsibility," that is, moral responsibility based on an individual's special knowledge. According to Whitbeck (1998), "for someone to have a moral responsibility for some matter means that the person must exercise judgment and care to achieve or maintain a desirable state of affairs." As Martin and Schinzinger (1996) note, the goal of responsible engineers is "the creation of useful and safe technological products while respecting the autonomy of clients and the public, especially in matters of risk-taking." In addition to a fundamental commitment to public health, safety, and welfare, engineering ethics is typically concerned with conflicts of interest, the integrity of data, whistle-blowing, loyalty, accountability, giving credit where due, trade secrets, and gift giving and bribes (Wujek and Johnson, 1992).

Many observers, such as political philosopher Langdon Winner, are critical of the traditional preoccupation of engineering ethics with specific moral dilemmas confronting individuals (Winner, 1990):

Ethical responsibility…involves more than leading a decent, honest, truthful life. . . . And it involves something much more than making wise choices when such choices suddenly, unexpectedly present themselves. Our moral obligations must . . . include a willingness to engage others in the difficult work of defining the crucial choices that confront technological society . . . .

Similar critiques of engineering ethics have been made by many others, including: Vanderburg (1995), an engineer himself who distinguishes between "microlevel" analysis of "individual technologies or practitioners" and "macrolevel" analysis of "technology as a whole"; and Ladd (1980), an ethicist, who argues that professional ethics can be delineated as "micro-ethics" or "macro-ethics" depending on whether the focus is on relationships between individual engineers and their clients, colleagues, and employers or on the collective social responsibility of the profession.

One response to these critiques would be to broaden the discussion of engineering ethics to include the ethical implications of public policy relevant to engineering, such as risk and product liability, sustainable development, health care, and information technology (Herkert, 2000b). Another approach, advocated by Lynch and Kline (2000; see also Kline, 2001), is to focus more on "culturally embedded engineering practice," that is, institutional and political aspects of engineering, such as "contracting, regulation, and technology transfer." Knowledge of such nontechnical, but nonetheless "ordinary," engineering practice, they argue, would provide engineers with the insight to anticipate safety problems before they escalated into technological disasters.

Engineering ethics is "professional responsibility," that is, moral responsibility based on an individual's special knowledge.

Political scientist E.J. Woodhouse (2001) also notes that engineering ethicists have traditionally overlooked macroethical issues, most notably, he argues, the problem of overconsumption. Woodhouse maintains that overconsumption requires the immediate attention of engineers, and he suggests alternative approaches to engineering ethics based on collective professional responsibility and the role of engineers as consumer-citizens.

Although traditional concerns are not likely to disappear or to be subsumed under these new paradigms, interest is growing in integrating ethics instruction into a broader framework that includes the social context of engineering.

Pedagogical Trends

Ethical Frameworks

The ethical frameworks for teaching engineering ethics have traditionally included engineering codes of ethics and the application of moral theories. Many engineers, among them Unger (1994), are staunch defenders of the utility of codes of ethics, although, at the same time, they acknowledge their limitations. Some philosophers, such as Ladd (1980), have been skeptical of the relevance and usefulness of codes, which, they argue, are largely self-serving and of little help when it comes to ethical reasoning. Other philosophers, most notably Davis (1998), place great stock in the usefulness of codes.

Recently, some philosophers have also begun to challenge the importance of ethical theory in coming to grips with ethics in applied settings, arguing that formal discussions of abstract moral theories are not necessary for teaching professional ethics and, indeed, might even be counterproductive because they may "turn off" practitioners who doubt their relevance. Whitbeck (1998) has gone so far as to argue that the problem-solving approach used in engineering design is a useful paradigm for solving ethical problems.

> *Some argue that the problem-solving approach used in engineering design is a good paradigm for solving ethical problems.*

The Case Method

The most popular tool in teaching engineering ethics is the case method (Harris et al., 2000). Cases can be long or short, real or fictional, technical or nontechnical; they may be available in print, online, multimedia, or video formats. Most cases are self-contained, but some include documentation, such as book chapters (and sometimes entire books), journal articles, news accounts, and primary source archives. Despite this variety, Davis (1999a) notes that case methods have several common characteristics, including encouraging students to express ethical opinions; encouraging students to identify ethical issues and formulate and justify decisions; and encouraging the "develop[ment] in students [of] a sense of the practical context of ethics."

High-profile cases used in teaching engineering ethics include the 1979 crash of a DC-10 in Paris that killed 346 people (Fielder and Birsch, 1992), the 1981 collapse of suspended atrium walkways at the Hyatt Regency Hotel in Kansas City that killed 114 and injured dozens (Pfatteicher, 2000), and the explosion of the Space Shuttle *Challenger* in 1986 (Pinkus et al., 1997).

These high-profile cases may be useful for attracting the attention of engineering students, but the typical ethical dilemmas encountered by most engineers are more mundane. Therefore, case studies of more commonplace events are also used in classrooms. For example, fictionalized reviews of actual cases considered by the National Society of Professional Engineers (NSPE) Board of Ethical Review involve conflicts of interest, trade secrets, and gift giving (NSPE, 2002).

Several ethicists, most notably Pritchard (1998), have called for the development of more cases that focus on "good works," that is, cases that demonstrate that making sound ethical judgments need not end with whistle-blowers being demoted or fired. One such incident is the case of William LeMessurier, a civil engineer who designed the CitiCorp Building in New York. When he discovered, after the building was in use, that it had not been properly constructed to withstand hurricane-force winds, he went to his partners and to CitiCorp and insisted that immediate action be taken to strengthen the building's structural joints (Online Ethics Center for Engineering and Science, 2002).

Engineering Ethics Resources

In the past decade, resources for engineering ethics education have increased considerably. Well-established textbooks have come out in new editions (Harris et al., 2000; Martin and Schinzinger, 1996; Unger, 1994), and new texts are periodically published (e.g., Gorman et al., 2000; Herkert, 2000b; Whitbeck, 1998).

The explosive growth of online materials and resources, including cases, course syllabi, instructional modules, codes of ethics, and essays, has been equally important (NCSU, 2002). The most extensive online resource is the Online Ethics Center for Engineering and Science, which includes material on a wide range of topics, such as engineering practice, responsible research, and moral leaders. The Center for the Study of Ethics in the Professions (2002) at Illinois Institute of Technology maintains an online version of its library of professional ethics codes that includes more than 850 documents. Several professional engineering societies, such as NSPE and IEEE (2002), also post codes of ethics and other relevant information on their websites.

Many educators use the Web's interactive capability as part of their teaching of ethics. For example, faculty and students at the University of Virginia have developed detailed, multimedia cases focusing on ethical issues in engineering design (Gorman et al., 2000). The goal of the project is to "develop and disseminate cases and supporting materials that teach students to exercise good judgment and moral imagination, that help them learn that design always entails an ethical perspective, and that demonstrate that environmental design is both challenging and viable" (Gorman et al., 1997).

Curriculum Models

The Required-Course Model

A few engineering programs have established required courses in engineering ethics for all students. Although this approach has been successful at Texas A&M (Rabins, 1998) and a few smaller institutions, because of high staffing costs and an already tightly packed engineering curriculum, the required-course model is unlikely to be widely used. In addition, unless a required course is supplemented by further instruction in ethics in mainstream engineering courses, this method may leave students with the impression that ethics is a sidebar rather than an integral part of their engineering studies.

Across-the-Curriculum Model

An alternative approach addresses the limitations of the required-course model by spreading ethics instruction throughout the engineering curriculum. The key to the success of this model is overcoming the resistance of engineering faculty to the importance of ethics instruction and demonstrating to them, through faculty development initiatives, how ethics material can be incorporated into their classes. Consider, for example, the engineering curriculum initiative at the University of Michigan, which is driven by the philosophy that the best way to develop and maintain an across-the-curriculum program is to make subtle changes in the way engineering is taught so that ethics and safety are seen as common attributes of good engineering practice (Steneck, 1999).

The across-the-curriculum program at Illinois Institute of Technology has focused on faculty development initiatives that help engineering faculty incorporate ethics material into their technical courses. As Principal Investigator Michael Davis notes (1999b), by focusing on ethical issues in ordinary engineering problems, this "pervasive method" can be implemented without relying on formal moral theory and without sacrificing coverage of technical material.

The across-the-curriculum approach, which of necessity involves the training and participation of more faculty than stand-alone required courses, clearly places ethics in the mainstream of engineering education. Sometimes though, because ethics material is often covered in small chunks in disparate courses, the subject may lack depth and continuity.

Integration of Engineering Ethics and Science, Technology, and Society

The ideal solution (where practical in terms of staffing requirements and room in the curriculum) is to use a combination of methods—a required course in engineering ethics and an engineering curriculum that recognizes the importance of ethics throughout. Educational research and anecdotal experience of faculty suggest that engineering students have both the motivation and the ability to engage material that deals with the social context of engineering. Therefore, a fruitful curriculum model would simultaneously address: (1) professional and ethical responsibility and (2) the societal context of engineering. This linkage would also address the criticism of traditional engineering ethics instruction, noted earlier, that it focuses on microethical problems—dilemmas confronting individual engineers—but neglects the macroethical issues related to the nature and development of technology.

The ideal curriculum includes a required course in engineering ethics and a recognition of the importance of ethics throughout the curriculum.

A successful example of this model is the Program on Technology, Culture, and Communication (TCC) at the University of Virginia School of Engineering and Applied Science. All engineering students take a four-course science, technology, and society (STS) core, which includes 7 to 22 weeks of ethics content, most of which is included in a two-course senior sequence, "Western Technology and Culture" and "The Engineer in Society" (Soudek, 1999). Integration with the overall engineering curriculum is achieved through required senior theses on the social impact of technical projects; these are overseen by members of the TCC faculty.

Accreditation Criteria and Engineering Ethics

Many ongoing developments in engineering ethics education have been influenced by recent changes in ABET's accreditation criteria. Engineering Criteria 2000 (EC 2000) promises to alter significantly the landscape of engineering education. One potential outcome of EC 2000 is increased attention to the ethical responsibilities of engineers and the societal context of engineering. Among other EC 2000 outcomes, "engineering programs must demonstrate that their graduates have…an understanding of professional and ethical responsibility . . . [and] the broad education necessary to understand the impact of engineering solutions in a global and societal context." As I have argued throughout this article, these two outcomes are closely linked.

Meeting the challenges posed by EC2000 will require curricular innovation, faculty development, and program assessment.

The Liberal Education Division (LED) of the American Society for Engineering Education has developed recommendations for addressing these and other liberal education outcomes under EC 2000. In an LED "white paper," Steneck et al. (2002) identify "professional responsibility" as one of four objectives of a liberal education; the other three are communication, technology and culture, and intellectual and cultural perspectives.

Continuing Challenges

Although significant progress has been made in bringing ethics into engineering education, much remains to be done. Meeting the substantial challenges posed by EC 2000 will require curricular innovation, faculty development, and program assessment. Ethicists will have to further refine their approach to research and teaching to make it more relevant to engineering design (Whitbeck, 1998) and practice (Lynch and Kline, 2000), as well as to the international context of engineering ethics (Weil, 1998).

The greatest challenge, however, confronts engineering faculty. Because required courses in engineering ethics are not likely to be widespread, it will be incumbent on the engineering community to ensure that ethical problems, standards of conduct, and critical thinking skills are developed in the context of technical courses. For education in engineering ethics to fulfill its promise, engineering educators must face head on the societal and ethical implications of engineering. This task, which must begin with self-education through reading, the use of online resources, discussions with colleagues, and, where available, faculty development seminars, will not be complete until engineering faculty are enthusiastic about and comfortable with discussing ethical issues and the social implications of technology with their students.

Acknowledgements

This article is an abridged and updated version of an earlier paper (Herkert, 2000a), portions of which draw upon my prior work.

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Engineers face complex moral issues that cannot be resolved by codes of professional behavior.

Machines, Modifications of Nature, and Engineering Ethics

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Ethics, to use the felicitous words Lord Bank uttered three-quarters of a century ago, can be called the "observance of the unenforceable." Ethics falls in the middle of the spectrum, with laws, norms, and codes at one extreme and good manners at the other. In Lawrence Durrel's Justine, Balthazar says, "morality is nothing if it is merely a form of good behavior." These two definitions provide as good a preamble as any to a discussion of engineering ethics. The enormously complex moral issues that confront engineers cannot be resolved simply by codes of good professional behavior (engineer to engineer and engineer to employer), important as they are. Engineers must also have a sense of the profound implications those issues have for our society, and for our species. Without that understanding, engineers risk floundering in a sea of moral dilemmas and ambiguities that can distort the immense power humans have achieved through engineering.

Engineering is a process of creating and using artifacts, that is, machines, that extend our biological capabilities; these include dams, engines, radios, and computers, to name but a few. The ethics of engineering is the ethics of that process. Any machine is, in effect, a modification of nature—the creation of something that did not exist before, something that would not exist without human intervention. Thus, the ethics of engineering is also the ethics of the modification of nature. Humans, of course, are not the only organisms that modify nature, but they are the only ones that do it through a reasoned set of skills. Neither is engineering the only human activity that modifies nature; agriculture, interventional aspects of medicine, and genetic engineering (as its name implies) are some of the others. Every biological organism, which is itself a part of nature, affects its environment by its very existence. Engineering artifacts magnify that impact by extending the reach and power and enhancing the drives of humans to such an extent that sometimes new global phenomena are created, on the surface of the earth, in the atmosphere, in the oceans, and in space.

The modification of nature through artifacts, whether tangible or intangible, is as ambitious a task as understanding nature, which is the goal of science. Although the two are intertwined and an understanding of nature, including ourselves, is essential to reasoned modifications of nature, the ethical problems of science and engineering are different. In science, they revolve largely around epistemological issues, such as how we go about knowing nature. The greatest ethical lapse in science is misconduct in research, the falsification of data or results that betrays the integrity of the search for truth. In engineering, the ethical problems are more nebulous because of the myriad purposes, methods, and consequences involved in modifications of nature and the creation of machines. Probably, the most glaring ethical lapses are in giving a false sense of security about the performance of a machine or overlooking potentially dangerous consequences and side effects. Examples range from exposing workers to machines that create a damaging level of noise to promulgating, endorsing, or applying a code or design the engineer knows to have dangerous limitations but lacks the courage to disclose (as happened on October 9, 1953, when Vajont Dam in the Alps gave way and, in a few seconds, wiped out an entire town of 2,000 people). Beyond the traditional issues of good professional behavior, most ethical questions in engineering can be grouped into four areas: modifications of nature; *cui bonum* (i.e., who benefits); methods and designs; and control of technology.

Modifications of Nature

After some four million years of nature-modifying human activities, we are still debating why we modify nature and whether it is good or bad, right or wrong. The impulse to modify nature through the creation of artifacts is as fundamental a human trait as the curiosity that underlies science. Other living organisms modify nature instinctively. We do it consciously, using engineering, medicine, and agriculture, following an impulse that is at the core of our identity. There is no *a priori* reason why, as a species, we should not become extinct like other species. In fact, the evolutionary process is a graveyard of biological designs. But our ability to understand nature through science and to modify it through engineering and purposeful design might, if we use them wisely, save us from that fate. In other words, our ability to modify nature might enable us to escape the strictures of purely biological evolution. Thus, the essential issue is not whether we should continue to modify nature, but how far we should go. This is a question of both science (our knowledge of nature) and engineering (our prowess in creating machines). But it is first and foremost a question of ethics, a search for guiding principles.

The impulse to modify nature through the creation of artifacts is a fundamental human trait.

Some of the questions related to the modification of nature are not immediately associated with the realm of professional engineering, but they are fundamental to the practice of engineering. And engineers are situated to perceive them from a distinctive vantage point because engineers are uniquely qualified to clarify the essence of machines—nature-modifying artifacts—and the ethical issues associated with them. This challenge has traditionally stymied philosophical inquiry, but the questions have become more urgent, particularly as more and more advanced machines are designed with characteristics akin to those of biological organisms, such as machines that can reproduce or replicate themselves and machines that have a kind of self-awareness. Engineers must become participants in ongoing discussions of these issues with scientists, philosophers, social analysts, historians, and urban planners.

Every machine brings with it the possibility of an unforeseen catastrophic event, either internal or external. The history of engineering disasters provides myriad examples, from the collapse of Roman bridges designed with piers too thick to accommodate exceptional floods to the explosion of TWA flight 800 to the tragedy of September 11. As we increasingly modify nature through machines that have not been tested in the crucible of evolution, we are placing ourselves further and further out on our evolutionary limb. How does one deal with the ethical issue of unfathomed or unfathomable consequences? These consequences are associated not only with machines designed for extreme environments, such as submarines, the space station, and pacemakers. Unforeseen consequences are also, and often more importantly, associated with simpler mass-produced machines, such as automobiles and televisions. Clearly, decisions about popular consumer products and major government systems both involve more than engineering; they also involve ethical, sociopolitical, and economic considerations.

Engineers have a responsibility to make their views heard in the public debate, something they have been reluctant to do. Engineers often choose to operate exclusively within the framework of engineer and employer or engineer and other engineers. Today, however, engineers are at a crossroads, and they must recognize the broad, ethical implications of their actions.

Engineers have a responsibility to make their views heard in the public debate.

The impact of machines on the environment and, ultimately, on the sustainability of the planet, touch on the entire spectrum of issues facing engineers. Increasingly powerful and numerous machines have exponentially increased the impact of human activity on the environment. Engineers, as part of the larger sociopolitical community, must decide how to proceed when the impact cannot be fully understood or predicted. Engineers should participate in discussions of how the immediate, burgeoning needs for housing, water, energy, transportation, and other necessities can be addressed without causing environmental alterations that will affect future generations and the future of the Earth.

Cui Bonum

Engineers must be aware of who will benefit from a particular modification, a particular design. Before the *Challenger* tragedy, some of the engineers had argued that the flight should not go forward, but the interests of supervisory management prevailed. What is the duty of engineers in such situations? *Cui bonum* questions confronting engineers go beyond intergenerational ethics, beyond the alterations of nature at the cost of long-term sustainability. The piercing, ear-damaging noise emitted by an ambulance helps speed patients to the hospital but is not good for bystanders. Similarly, the noise of an airplane speeding passengers to a destination can be injurious to people living under the flight path. Should engineers do their utmost to mitigate these effects? Should mitigation prevail over other considerations?

These issues have been addressed by legislators and economists, but they are also ethical issues for engineers. Legislative measures, although necessary, are not sufficient to resolve them. Should engineering firms build projects in countries suspected of harboring terrorists? If these projects strengthen potential adversaries, is it ethical for engineers to build them? Enduring ethical questions also relate to the building of weapons, particularly weapons that can cause uncontrollable collateral damage or that have widespread global impacts. These are pressing questions for engineers of all nations.

The traditional human-centric belief at the heart of the engineering enterprise is that humans have a right to modify nature. But we must also consider the impacts of engineering on other species. Who benefits? We are becoming increasingly aware of the importance of other organisms to our own long-term survival, but is this the only reason we should preserve other species? Beyond utilitarian motives, do we have a responsibility to other living organisms? Montaigne addressed this question more than four centuries ago, "We poorly argue the honor and duty of an action from its utility and we commit fallacy in thinking that everyone is obliged to perform, that it is honorable for everyone to perform, an action merely because it is useful."

The impacts of engineering affect many populations, from individuals to nations, the natural world, the climate, and the entire planet. In doing right by one group, we may do damage to other groups. Engineers must begin to debate their ethical responsibility to improve the conditions of populations up and down the scale. A host of technologies, from water purification to radio, have benefited the entire world and helped preserve other species. Engineers should ask themselves if they have an ethical responsibility to help eradicate the endemic scourges of poverty and disease.

Methods and Designs

Beyond questions about the purpose and extent of modifications loom ethical questions associated with the methodology of modifications—with engineering design. Methodology has become so complex that it sometimes interferes with a clear understanding of purpose. Machines extend the reach of humans, and, if they are well designed, their performance, unlike the performance of humans, should be fully predictable. However, we are beginning to create machines of such complexity, such as computer programs, that they are not fully testable. Under what conditions is it ethical to design machines with unpredictable behavior? Is it ethical to rush machines to market that have not been fully tested or that we know (or suspect) have defects in performance? These questions touch on often subtle conflicts between reducing costs and creating better or safer machines.

Control of Technology

The question of whether and how to control the creation and use of technology raises ethical issues of great concern to society. The issues for science and engineering have many parallels. Should science be pursued for its own sake? Is it ethical to control access to knowledge? In engineering, the issues include technological determinism and runaway technology—the "if it can be built, it will be built, no matter what" of Robert Moses' late period. They also encompass questions of access to engineering education for women and minorities and who controls standards and codes.

Not all questions involving the modification of nature are in the unenforceable domain of ethics. Many have been addressed through legislation, which is based on ethical principles of right and wrong. But laws reach only so far. Some actions that are legal may be unethical in the context of the special problems facing a profession or the action of an individual. Cases identified as professional misconduct, which may be patently unethical, may or may not fall within the domain of the law. Ethics are needed to provide the brake that law may be unable to provide. In a recent legal ruling, for instance, a court ruled that knowledge of unsafe conditions was not enough to prove liability; but the ethical question remains.

Systems of checks and balances, both formal and informal, have been established, and governments at all levels, professional societies, and the media have endeavored to address these issues. But these mechanisms cannot be sufficient in all circumstances. We need ethical guidance that harkens back to the fundamental questions of why and how far we should modify nature and to whose advantage. A recent example of the insufficiency of formal mechanisms and the need for this guidance was encountered in the evacuation of the World Trade Center towers on September 11. The difficulties were apparently exacerbated by a building code set by the owners that called for narrower stairways.

We can now create machines of such complexity that they are not fully testable.

Engineering Ethics for the Future

Ethics was originally in the domain of religion. In the West, beginning with the Greeks, it was also a subject of philosophical inquiry. Eventually, new views of the world were shaped, largely thanks to scientific thinking and discoveries, and with them came new ethical questions. Today engineering, as the motive force of technology, has raised pressing new ethical issues—especially as engineering begins to focus inward on the body. Artificial organs, tissue engineering, and genetic engineering have blurred the boundary between machines and biological organisms, raising a host of new ethical questions.

Developing a coherent engineering ethics out of the enormously complex, intertwined ethical questions facing engineers today will be extremely difficult. To be true to the great responsibility of extending our biological capabilities, ethics of engineering must go beyond broad generalities and codes of professional good conduct modeled after the Hippocratic oath. Ethics of engineering for the twenty-first century must also endeavor to address intelligent modifications of nature, technological determinism, access to the profession, conflicts and inequities of technology, the balance between global risk and safety, global sustainability, and engineering designs of machines with unpredictable performance. And they must address the responsibility of engineers to participate actively in debates about the human condition and the future of our species.

No doubt we have come a long way from the limited idea of ethics reflected in older engineering codes. If one considers the tens of millions of people who were killed in the last century by weapons designed by engineers, we have also come a long way from the naive definition of engineering as the application of science for the benefit of humankind. At this moment, we have no simple, overarching principle, no simple definition of the "good" to guide us through the maze of complex technologies. A coherent, comprehensive engineering ethic will have to be built patiently, stone by stone, case by case, and then continuously tested and reexamined in the context of very rapid technological and social change. This is an enormous and urgent challenge.

As the world changes, the definition of professional morality must change with it.

Engineering Ethics: The Conversation without End

Samuel C. Florman

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Engineering ethics again? Haven't we settled this business once and for all? Well, no. We seem to be engaged in a conversation that will never end, and properly so. As the world changes, so do the problems of defining professional morality. There has been—and continues to be—meaningful change in engineering ethics, more than one might intuitively have supposed. For example:

In the not too distant past, codes of engineering ethics very much resembled guild rules that told engineers how they should deal with each other. Don't compete for commissions on the basis of price. Don't advertise. Don't review a fellow engineer's work without first getting clearance from him. Today we might call such admonitions professional protocol, professional manners, or professional decorum. But society at large will not accept them as having anything to do with real ethics. In fact, in the 1970s, society at large, acting through the U.S. Department of Justice and the courts, declared such restrictions violations of antitrust laws, which radically changed the status of many professions—not only engineering. What engineers used to call ethical behavior is now to a great extent illegal.

I hope and trust that engineers will continue to behave courteously. Cutthroat competition between engineers is not in anybody's best interest, no matter what the antitrust laws say. But it is a fact that engineers can no longer hope to control their profession totally from within. The law will not permit it, and in a democracy this is fitting as well as inevitable. Once upon a time, the cowboy in a white hat walking down Main Street with guns at the ready was a hero. Today he is a vigilante. Frontier conditions no longer prevail.

The proliferation of laws, and the agencies to administer them, is a splendid example of democracy at work.

It is striking to note how many topics that used to be in the province of professional ethics are now in the province of law. Confidentiality, industrial secrets, and proprietary interest in invention are now defined by statute and legal precedent rather than by ethical codes. So are the norms of behavior considered appropriate for a professional. When an engineer in New York paid invoices from a firm that had performed no services for him, and it was discovered that this was done to make a covert political contribution, the commissioner of education suspended the engineer's state license, an action that was upheld by the Appellate Division of the New York Supreme Court.

And this is only a small part of the story. Consider the matter of product safety. Ironically, as engineers became more and more concerned about the ethical aspects of this issue, government regulation began to dominate the field. There was a time, to be sure, when a morally principled engineer was often the only protection on which the public could rely. The rule of the land was *caveat emptor,* buyer beware; Congress believed it was prohibited by the Constitution from telling manufacturers how to manage their affairs. In the nineteenth century, Senator Thomas Hart Benton, arguing against legislation intended to reduce the risk of steamboat explosions, proclaimed that the proper way to tell if a boat was safe was to inquire personally as to whether the machinery was in good working order. The "good old days" were really wild, woolly, and relatively lawless. Robber barons single-mindedly pursued profit, and a swarm of rapscallions, exemplified by snake-oil salesmen, plied their wares with little or no restraint. In such a climate, discussions of engineering ethics often revolved around the question of how engineers could maintain their independence from industry in order to safeguard society.

However, as the nation became wealthier and better educated, the communal will decreed that laws be passed and that rules and regulations be established to defend the public interest. Progress was slow and halting, but in the end, relentless. In 1852, Congress enacted a law that required the inspection of steam boilers. In the 1880s, there came railroad safety legislation. Between 1880 and 1906, 103 bills were introduced proposing control of interstate traffic in food and drugs, until finally the Pure Food and Drugs Act was passed and signed by Theodore Roosevelt. The Federal Trade Commission Act was passed in 1914, the Federal Power Commission founded in 1920, the Federal Communications Commission established in 1934, and the Civil Aeronautics Board in 1938. Finally, starting in 1970, after the first celebration of Earth Day, the floodgates were opened. A list of some of the better known protections tells the tale: occupational safety and health (1970); boat safety (1971); insecticide, fungicide, and rodenticide (1972); marine protection, research, and sanctuaries (1972); consumer products safety (1972); noise control (1972); safe drinking water (1974); motor vehicle safety (1974); hazardous materials transportation (1975); toxic substances control (1976); solid waste disposal (1976); clean air (1977); mine safety and health (1977); water pollution control (1977); comprehensive environmental response, compensation, and liability (1980).

The proliferation of these laws, and the agencies to administer them, is a manifestation of the public will and a splendid example of democracy at work. They show that the declaration in engineering codes of ethics to "protect the public interest" were much too vague to be useful (except as a general commitment to do one's best.) Yet, clearly legislation was not intended as a rebuff to engineers. In fact, engineers played a crucial role in drafting the acts that today protect the body social from disease, injury, and disaster. We cannot expect to enjoy the benefits of high technology and the fruits of a competitive economy without facing up to the complexity—yes, the often annoying complexity—that is inherent in them.

And complexity is an understatement when we consider the multitude of problems that are the consequences of our astonishing technological exploits. We all want safety, reliability, an undamaged environment, and undepleted resources. We also want economy—in fact, this is a moral imperative because it means more benefits for people of modest means. We want freedom and privacy, but also the benefits of technologies that threaten freedom and privacy. Surely the trade-offs that must be made cannot be left to the "free market," and surely the problems go beyond anything that can be determined by engineers, no matter how well intentioned they are. Engineers are committed to educating the public, presenting the facts clearly and correctly. But—unlike the days of Senator Benton—the basic technological decisions today must ultimately be subject to the public will, which means subject to the approval of politicians and bureaucrats.

An integral part of engineering progress has been the development of many thousands of technical standards. These standards constitute an engineering triumph—a glory of our civilization, comparable to the development of regulatory laws and agencies. In fact, these two marvelous phenomena are interrelated. Voluntary standards are developed by professional groups, and then government agencies, when they see fit, adopt the standards and give them the force of law. Without these laws, regulations, codes, and rules, each engineer would be given unwarranted—and unwanted—powers (and, incidentally, each engineering problem would entail reinventing the wheel).

We must constantly work to make our regulatory apparatus more efficient. This is a special challenge for engineers who choose to go into government service. And we must constantly preach self-discipline. Even with laws and regulations, we need self-discipline in the form of scrupulous compliance. Yet self-discipline is no substitute for restraint by government. The American founding fathers knew this and said it—frequently and eloquently. It simply took a while to apply the concept to technological activities.

Of course, it would be impossible—and undesirable—to subject every engineering decision to a written regulation. The next line of defense, however, is not the ethics of engineers, but rather the standards of liability as made manifest by our courts. And here, too, there have been meaningful changes in recent years. How safe is safe enough? What is the *expectation* of the citizenry in the area of risk and responsibility? Beyond the limits of legislation, the decisions of judges and juries govern. We do not say to industry, "be ethical." That is too vague and permits an enormous range of individual responses. It is an invitation to chaos. We say instead, "be prudent, and here are the standards by which you will be judged."

An industrial firm can be held liable for defective product design, defective manufacture, inadequate labeling, and faulty packaging. Liability losses can be suffered by companies that fail to keep proper records of product sales and distribution or fail to keep adequate records of project failures and customer complaints. As stated by the authors of *Product Safety and Liability: A Desk Reference*, "The one choice engineers, designers, and their employers no longer have is whether or not to pursue safety goals. To ignore or pay only lip service to safety . . . can jeopardize corporate survival" (Kolb and Ross, 1980).

Product safety is no longer a matter of conscience and good will. It is a professional specialty founded in knowledge of prediction techniques, fault tree analysis, failure modes, effects analysis, and the operator-design interface. When it comes to establishing liability, worthy intentions no longer count. Tort law traditionally required that negligence be proved as a "proximate" cause of an injury. But, since the 1960s, courts have been imposing "strict liability" for injuries caused by dangerous products *whether or not* negligence was involved. Nor is industrial pollution mainly a matter of ethical integrity as it once was. Most of the major environmental protection laws include provisions that permit private suits; so in addition to penalties that can be imposed by government agencies, the increasingly powerful environmental organizations have access to the courts.

We want freedom and privacy, but also the benefits of technologies that threaten freedom and privacy.

The problems of the Information Age—who should control the Internet and how—are still too new for us to predict their resolution. This is also the case with genetic engineering, terrorism, and the other technological problems that seem to arise almost daily. But it is clear that all of our old assumptions and beliefs—including engineering ethics—will be subject to continual challenge and reevaluation.

Yet some people—especially among the professional ethicists—are reluctant to accept the changes that have occurred. When a respected historian of technology, Edwin T. Layton, Jr. (1983), calls for engineers to become a "loyal opposition" within corporate America, I feel that he is expressing the precepts of an earlier age. Surely he means well; but by setting "good" engineers against "bad" entrepreneurs, I fear that he, and like-minded colleagues, may be doing more harm than good. First of all, if the objective is to protect the public welfare—which everyone agrees is the central objective of engineering ethics—such moralists have the wrong target in their sights. Several in-depth studies have shown that the overwhelming preponderance of technological disasters are caused, not by evil design—by greed or intent to deceive—but by ignorance, carelessness, negligence, and the like. A well intentioned, even saintly engineer may still be an inept engineer, that is, a "bad" engineer if his work does not serve the public well. Engineering ethics is not the same as conventional ethics. It is always worth preaching sermons on behalf of virtuous behavior. We must continually remind young people—and ourselves—that it is important to resist temptation and "do the right thing." But, in technical work, the facts show that competence does more good than "goodness," that incompetence does much more harm than evil intent. It is deceptive to imply that we can serve society by meaning well.

A well intentioned engineer may still be a "bad" engineer if his work does not serve the public well.

It is also unfortunate that academics who stress the importance of being constantly on guard against malfeasance risk nourishing feelings of suspicion and mistrust among their students. Yes, to repeat, we must be alert to the possibility of encountering evil in the world. But do we have to dwell on this endlessly in classes, conferences, and lectures? One hopes that young engineers can enter into their professional lives, not filled with foreboding and suspicion, but energized with enthusiasm and hope.

Whistle-blowing—to use a word that appears early and often in many discussions of engineering ethics—is a rare and extreme circumstance, worthy of consideration, to be sure, but not deserving of the central role it has been given in studies of the field. In this day and age, most enlightened organizations have an ombudsman system, or equivalent, to deal with employee grievances and alarms on a confidential basis. Development and maintenance of such systems is a key element of competent—and responsible—management. We will never eliminate the need for honorable and courageous people willing to endure martyrdom on behalf of public well-being. But a society that relies upon such martyrdom from its citizens is neither wise nor noble.

By dwelling on ambiguities and constant change, I do not wish to voice support for cynicism, of which there is no shortage. But, isn't it true that many debates that are nominally about engineering ethics are really expressions of personal prejudice and political commitment?

Of course, engineers are entitled to express their personal opinions. And clearly they have an ethical right to choose a line of work consistent with their political views. But this does not give them the license to allow their prejudices to overwhelm their professional discernment. Today, for example, an issue that divides the citizenry, engineers included, is the question of whether or not to drill for oil in the wildlife preserves of Alaska. Passions run deep, and it is sometimes difficult to remember that, as has been said in the Senate, "We are Americans on both sides of the aisle." I suppose that most engineers working for the oil companies favor drawing upon this resource, while most engineers working for environmental groups favor the reverse view. This need not be so in all instances, however, nor should it be. What is required of all engineers, however, is accuracy and truthfulness in all the work they perform.

It would be marvelous if every engineer could work for a cause in which he or she believed deeply. But the world being the way it is, this is not always possible. I am a builder, and I may wish to build a museum, a library, or a hospital. But it is morally acceptable for me to build a store or an office building, or even a gambling casino where casinos can be lawfully built. In fact, just as each citizen is entitled to legal representation, one can argue that every lawful enterprise is entitled to engage advice from professional engineers.

I remember how, at the height of the Cold War, the Institute of Electrical and Electronics Engineers used to conduct polls among its members about who was well satisfied to work on armaments, who was uneasily willing, who was not willing, etc. The results showed large percentages in each of the categories, just one example of the obvious fact that engineers are human beings.

Inevitably someone will raise the example of Nazi Germany and the work of engineers in designing and building death camps. To this, one can only say that absolute evil should be resisted wherever it is encountered, by all citizens, including, but not limited to, engineers. However, because such extreme examples—although they are worthy of discussion and should never be forgotten—are associated with wicked despotism, they need not form the core of deliberations by American professionals.

I propose that when engineers discuss ethics they avoid a simplistic approach that is no longer adequate to the complexities of the current day. This does not mean they should abandon their professional commitment to moral principles. However, I propose that the essence of engineering ethics be recognized as something different and apart from white-hat heroics. There is no single word that defines this "something," but *conscientiousness* is fairly close to what I have in mind. Engineers should be constantly aware that their fellow citizens are relying upon them. As a consequence, if they do their jobs well, they are acting more than competently. In serving their fellow human beings, and serving them well, they are acting righteously. Reliability is a virtue. Therefore, the conscientious, effective engineer is a virtuous engineer. It is superfluous to give specific admonitions such as, "Don't falsify test reports." The conscientious engineer must be, by definition, truthful, factual, alert, accurate—all key elements of any definition of ethical behavior. And, in a world where poverty and destitution are still widespread, a creative engineer—an engineer who alleviates hunger and suffering—becomes a towering force for moral good.

Much more can be said, to be sure. Individual engineers are uniquely qualified to perform *pro bono* work in their communities—and beyond. Also, through their professional societies, engineers have an opportunity (and a responsibility) to call attention to technological problems and to propose solutions—to commission studies, issue reports, set standards, schedule seminars, visit schools, and so forth. The role of the engineer has changed through the years, and it is well worth studying the nature of these changes and coming to terms with the new social order. But the opportunities to do good, particularly in organized groups, have not diminished.

Unfortunately, less than a third of U.S. engineers belong to any professional society at all. This seems to me to be a very good topic with which to continue the discussion about engineering ethics—the conversation without end.

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Engineering tools and techniques can be used to advance health care.

The Physiome Project: The Macroethics of Engineering toward Health

James B. Bassingthwaighte is a member of NAE and professor of bioengineering, biomathematics, and radiology at the University of Washington.

James B. Bassingthwaighte

In an overview of the state of engineering in the new millennium, Wm. A. Wulf (2000), president of the NAE, introduced the concept of "macroethical" behavior, that is, behavior that increases the intellectual pressure "to do the right thing" for the long-term improvement of society. Examples abound: the development of maintainable energy resources, the preservation of a healthy environment, the avoidance of ecological disasters, and universal education. The macroethical issue addressed in this article focuses on using engineering to advance health care, minimizing risks and maximizing benefits. I believe we have a duty to "think as hard as we can" (in Wulf's words) to plan for the future by using engineering strategies wisely and responsibly.

Current risk/benefit analyses of potential new drug therapies are not sufficient to the task. In general, current analyses are based on the inference that a drug acts on a single protein, usually an enzyme or a transporter; efficacy and side effects are determined later by observation. We need a great leap forward that will enable us to make "knowledgeable" calculations of risks and benefits. We need information on which decisions can be based. In the United States, new technologies, such as gene-insertion, stem-cell infusion, and new pharmaceuticals are within the purview of regulatory agencies, such as the Food and Drug Administration, rather than scientific funding agencies. The mission of regulatory agencies is to protect us against speculative or risky advances. These agencies depend heavily on large, expensive clinical trials in which some human subjects are put at risk in the interest of protecting others. For novel interventions, which offer great possibilities but little evidence for predicting success and a high risk of failure, harm, or damage, we must find another way to move ahead, but with minimal risk. In other words, we must find ways that enable us to follow our intuition and insight by maximizing our ability to predict risks and benefits.

Informatics and Information Flow

The problem in medicine and biology is that much relevant information is either irretrievable or undiscovered. Even a complete human genome cannot define human function. In fact, it is only a *guide* to the possible ingredients. The genetically derived aspects of the genome (i.e., proteins) are much more numerous than the genes. To get an idea of the magnitude of the problem, consider that yeast has about three proteins per gene, and humans have about 10 proteins per gene. Pretranslational selection from different parts of the DNA sequence, the post-translational slicing out of parts of the protein, the splicing of two or more proteins together, and the combining of groups of proteins into functional, assembly-line-like complexes, all contribute to the variety of the products of gene expression. Even a completely identified proteome, which is still beyond the scientific horizon, will be like a list of the types of parts of a jumbo jet with no indication of how many should be used or where they go. The concentration of proteins, the balance between synthesis and decay in each cell type, is governed by environment, by behavior, and by the dynamic relationships among proteins, substrates, ionic composition, energy balance, and so on and, thus, cannot be predicted on the basis of the genome.

The identity and descriptions of proteins, their locations, and concentrations in various cell types under various conditions and the kinetics of the reactions in which each is involved would fill a huge database. The protein data banks (e.g., PDB, 2002; Swissprot, 2002) are giant stepping stones that provide amino acid sequences and many protein structures but little data about function. Newer enzyme databases (e.g., WIT, 2002) are oriented toward providing kinetic or functional information, but they cover single-cell species better than mammals (Reich and Sel'kov, 1981).

The Combinatorial Dilemma

Sorting out the genome will leave us with a huge number of proteins to think about. The estimates of the number of genes have come down by about half from earlier estimates of 60,000 to 100,000; because new ones are also being found, 50,000 is a reasonable estimate. The level of complexity in mammalian protein expression far exceeds that of *C. elegans*, which has 19,536 genes and 952 cells. Humans might only have two or three times as many genes, but probably have a much higher ratio of proteins per gene. Assuming 10 proteins per gene, we have on the order of a half million proteins in widely varied abundance, and each protein has several possible states. If a protein in a given state interacts with only five other proteins (e.g., exchanging substrates with neighbors in a pathway or modifying the kinetics of others in a signaling sequence), then it may "connect" to any other protein through only a few links, a kind of "six degrees of separation" from any other protein. Moreover, cells contain not just proteins, but also substrates and metabolites, and they are influenced by their environments. Given the possible permutations and combinations of linkages and the many multiples further in the dynamics of their interactions, the combinatorial explosion would appear to preclude predictions.

The problem in medicine and biology is that much relevant information is either irretrievable or undiscovered.

Managing Complexity

The complexity I've briefly described provides a basis for functionality that cannot be predicted from knowledge about each of the components. "Emergent" behavior is the result of interactions among proteins, subcellular systems, and aggregates of cells, tissues, organs, and systems within an organism. Physiological systems are highly nonlinear, higher order systems, and dynamics are often chaotic (Bassingthwaighte et al., 1994; Goldbeter, 1996). Chaotic systems are only predictable over the short term; but they have a limited operating range. Even when Bernard (1865, 1927) defined the stability of the "milieu interieure," he meant a mildly fluctuating state rather than a stagnant "homeostasis." Biological systems are "homeodynamic"; they fluctuate, but under control, and they are neither "static" nor "randomly varying."

By "complexity" we imply that, even if we knew all of the proteins and all of the rate constants for their reactions, we could not predict the long-range outcome of an intervention that targeted only one protein. However, behavior can be predicted for the short term. Side effects show up later. Because proteins are building blocks (or nodes) on pathways and because each protein reacts with substrates or other proteins of a limited variety, there are road maps of reactions, the charts of biochemical reactions. The known stoichiometry of reactions (the numbers of moieties combining to form products) is the basis of flux/balance analysis for estimating product formation in bacterial cultures (Schilling et al., 2000). However, because evidence on thermodynamics is generally lacking, we cannot limit the predicted range of responses (Beard et al., 2002). Our ability to predict responses is handicapped by missing reactions, unidentified proteins, and the paucity of information about reaction rates (or traffic flow), controllers of the enzymes or transporters, and how proteins are arrayed spatially. Molecular biologists are learning how gene expression is regulated to adapt over long periods of time. But "thinking hard" will require much more data, at the single protein level and at a succession of higher levels.

For models of systems that convey real understanding, we will need to use engineering approaches.

Bioinformatics

This vast array of information must be linked into a consistent whole. The databases must be well curated and easily accessible, and they must provide a substrate for behaviorally realistic models of physiological systems. The arguments for building large databases to capture biological data are fairly new (Dao et al., 2000; Weissig and Bourne, 1999). Federal funds support genomic and proteomic databases, but not databases of higher level physiological information. Organ and systems data acquired over the past century have not been collected in databases and are poorly indexed in the print literature. Providing searchable texts of articles online will help but will not be a substitute for organized databases. The Visible Human Project, the National Library of Medicine's effort to preserve anatomic information (NLM, 2002) is a part of the *morphome* (which we define as providing anatomic and morphometric information), analogous to the genome and the proteome.

The genome, proteome, and morphome all concern structure, which is necessary but not sufficient for explaining function (the physiome). We need to know about the dynamics, kinetics, and functioning of those structures and how they interact. Physiology and pathophysiology concern processes, not fixed states. We need more than statistical descriptions of associations among physiological variables; we need models that include mechanisms and distinguish mere association from cause and effect.

All of this information must then be captured in a comprehensive, consistent, conceptual framework, that is, a model of the system that conveys understanding, and for this we will need to use engineering approaches. Understanding complicated systems, modeling them, and learning the tricks for reducing their complexity to attain computability, are in the engineering domain, and bioengineering-trained investigators will be the integrators of the future.

Of course, all models are incomplete. They come in a variety of forms, such as sketches of concepts, diagrams of relationships, schemas of interactions, mathematical models defined by sets of equations, and computational models (from analytical mathematical solutions or from numerical solutions to differential or algebraic equations). The behavior of a well developed, well documented computer model can give us some insight into the behavior of the real system.

The Macroethical Imperative

Although we cannot predict the outcomes of drug therapy with certainty, we must go ahead. Despite the risk, designers of pharmaceuticals to alleviate AIDS or Alzheimer's disease, developers of stem cells modified to cure diabetes, and producers of materials for the prolonged, controlled release of drugs all have an obligation to move forward into the unknown. Every new bit of information reveals our ignorance of other information, and the maze of possibilities is impossible to fathom with the unaided mind. Computational tools for large-scale models are being developed and are anxiously awaited by biologists. Computers, even big, multi-CPU parallel machines, are still too slow to be much good as "mind expanders." We need computers that can answer our "what ifs" in the time it takes us to think of the next question. Only then will we be able to critique efficiently the behavior of the models.

We must do our utmost to predict well, not just the direct results of a proposed intervention, but also the secondary and long-term effects. Thus, databasing, the development, archiving, and dissemination of simple and complex systems models, and the evaluation (and rejection or improvement) of data and of models—are all part of the moral imperative. They are the tools necessary to thinking in depth about the problems that accompany, or are created by, interventions in human systems or ecosystems.

The Physiome and the Physiome Project

A *physiome* can be defined as the quantitative description of the functional state of an organism. A quantitative model is a way of removing contradictions among observations and concepts and creating a consistent, reproducible representation of a system. Like the genome, the physiome can be defined for each species and for each individual within the species. The composite and integrated system behavior of the living organism is described quantitatively in hierarchical sets of mathematical models defining the behavior of the system. The models will be linked to databases of information from a multitude of studies. Without data, there is nothing to model; and without models, there is no source of deep predictive understanding.

The Physiome Project provides one response to the macroethical imperative to minimize risk while advancing medical science and therapy (Bassingthwaighte, 1995; Bassingthwaighte et al., 1991). The project is an effort to define the physiome, through databasing and modeling, of individual species, from bacteria to man. The project began with collaborations among groups of scientists in a few fields and is developing spontaneously as a multinational collaborative effort (Bassingthwaighte, 2000). Investigators first defined goals and then proceeded to put pieces together into impressive edifices (e.g., Hunter and Smaill, 1988; McCulloch et al., 1998; Noble and Rudy, 2001; Popel et al., 1999; Rudy, 2001; Winslow et al., 2000). Via iteration with new experimentation, models can remove contradictions and demonstrate emergent properties. These models are part of the tool kit for the "reverse engineering" of biology. The scale of the models, like the scale of models for weather prediction, presents computational grand challenges.

The Physiome Project is not likely to result in a virtual human being as a single computational entity. Instead, small models linked together will form large integrative systems for analyzing data. There is a growing appreciation of the importance, indeed the necessity, of modeling for analysis and for prediction in biological systems as much as in physical and chemical systems.

The hierarchical nature of biological systems is being used as a guide to the development of hierarchies of models. Models at the molecular level can be based on biophysics, chemistry, energetics, and molecular dynamics, but it is obviously not practical to use molecular dynamics in describing the fluxes through sets of biochemical pathways, just as it is not practical to use the full set of biochemical reactions when describing force-velocity relationships in muscle, or to use the details of myofilament crossbridge reactions when describing limb movement and athletic performance. One cannot build a truck out of quarks.

Without data, there is nothing to model; and without models, there is no source of deep predictive understanding.

Biological models can be defined at many hierarchical levels from gene to protein to cell to organ to intact organism. Practical models comprised of sets of linked component models, each somewhat simplified, represent one level of the hierarchy. The strategy is to avoid computing the details of underlying events and to capture, at the higher level, the essence of their dynamic behavior. But monohierarchical models are not necessarily built to adapt to changes in conditions. Handling transients is like using adjustable time steps in systems of stiff equations, but more complicated; the lower level model must be used to correct the higher level representation. Once we have very good models that extend from gene regulation to the functions of the organism, they can be used to predict the short-term and long-term efficacy and side effects of various therapies.

Like genomic information, biological information and models should be put in the public domain. Parochial attitudes and financial interests should not be allowed to interfere with open access to knowledge and the scientific developments dependent on that knowledge. Obviously, success will require collaborative efforts; no individual investigator or group can make this happen.

Undertaking large-scale systems bioengineering, such as the Physiome Project, is a macroethical imperative.

The Physiome Project has its own risks and benefits. It is expensive to build, maintain, and revise immense databases. Improving the quality of information and learning how to provide good databases will be more difficult than sequencing the genome. One obvious benefit will be better therapies, by reducing catastrophic errors (e.g., predicting the effects of thalidomide on embryonic development) and by reducing the costs of bringing new drugs to market. This will take several years. As a society, we have decided that it is unethical to take large risks with human subjects; and we know that offsetting these risks will require national and international investment. Therefore, undertaking large-scale systems bioengineering, such as the Physiome Project, is a macroethical imperative.

Acknowledgement

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NAE News and Notes

NAE Newsmakers

Andreas Acrivos, Einstein Professor of Science, Emeritus, City College of the City University of New York, received the **National Medal of Science** on June 12, 2002. Dr. Acrivos was honored for helping establish the field of suspension mechanics relevant to oil production and semiconductor manufacturing processes.

Yvonne C. Brill, aerospace consultant, was awarded the **2002 IEEE Judith A. Resnik Award**. Ms. Brill received the award for innovations in rocket propulsion systems.

Joseph M. Colucci, president, Automotive Fuels Consulting, Inc., is the 2001 recipient of the **Edward N. Cole Award for Automotive Engineering Innovation** presented by the Society of Automotive Engineers. Mr. Colucci was recognized for his pioneering work on the catalytic converter, unleaded gasoline, and reformulated gasoline.

Thomas E. Everhart, president emeritus, California Institute of Technology, was awarded the **2002 IEEE Founders Medal** for contributions in scanning electron microscopy and for leadership in academia, service to engineering organizations, and outstanding advice to the nation and industry.

Arun N. Netravali, chief scientist, Bell Laboratories, Lucent Technologies, and **Jerry M. Woodall**, C. Baldwin Sawyer Professor of Electrical Engineering, Yale University, were among the **2001 National Medal of Technology Laureates** recently announced by President George W. Bush. Dr. Netravali was recognized for his leadership in the field of communication systems; for pioneering contributions that transformed TV from analog to digital technology, enabling numerous integrated circuits, systems, and services in broadcast TV, CATV, DBS, HDTV, and multimedia over the Internet; and for technical expertise and leadership, which have kept Bell Laboratories at the forefront in communications technology. Dr. Woodall was recognized for his pioneering role in the research and development of compound semiconductor materials and devices and for the invention and development of technologically and commercially important compound semiconductor heterojunction materials, processes, and related devices, such as light-emitting diodes, lasers, ultrafast transistors, and solar cells.

The World Technology Network has voted **Karl S. Pister**, Roy W. Carlson Professor of Engineering, Emeritus, University of California, Berkeley, winner of the 2002 (Individual/Corporate) **World Technology Award for Policy**. The current members (430) of the World Technology Network chose Dr. Pister from a list of 100 eminent candidates from 20 technology-related fields. Dr. Pister was honored for his leadership in educational outreach and for creating opportunities for educationally disadvantaged students.

John M. Prausnitz, professor of chemical engineering, University of California, Berkeley, received the **Rossini Award for Excellence in Applied Chemical Thermodynamics** from the International Union of Pure and Applied Chemistry (IUPAC) at its meeting in Rostock, Germany, July 2002.

Joanne Simpson, Goddard Senior Fellow and chief scientist for meteorology, NASA Goddard Space Flight Center, was awarded the prestigious **International Meteorological Organization Prize** by the Executive Council of the World Meteorological Organization (WMO). Dr. Simpson, the first woman ever to win this prize, was recognized for her 51 years of pioneering work on cloud modeling, observational experiments on convective cloud systems, and hurricane research. She was also honored for participating in the aircraft aspects of several experiments by the WMO Global Atmospheric Research Programme (GARP) and for helping to establish a basic understanding of tropical circulation and heat balance.

Ivan M. Viest, president, IMV Consulting, was honored with the title **Doctor Honoris Causa** at a celebration of the Technical University of Košice in Slovakia marking the fiftieth anniversary of its founding and the twenty-fifth anniversary of the establishment of its Civil Engineering Department. Dr. Viest was honored for significant contributions to the development of the theory and methods of design of civil engineering structures and for effective cooperation with scientific research entities in the Slovak Republic, with special emphasis on cooperation with the civil engineering faculty of the Technical University of Košice.

The New National Academies Building

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On July 1, 2002, the 25-person NAE Program Office moved from 2101 Constitution Avenue to the new National Academies building at 500 5th Street, NW, Washington, DC 20001. The building, located between 5th and 6th streets and across from the MCI Center and the National Building Museum, is convenient to three Metro stops (Gallery Place/Chinatown, Judiciary Square, and Archives/Navy Memorial). The 11-story building now houses approximately 1,000 people from the Harris-Green complex, the Foundry Building, 1000 Thomas Jefferson Street, and 2101 Constitution Avenue. Five levels of underground parking can accommodate approximately 440 vehicles.

Besides staff offices and workstations, the building has 16 state-of-the-art conference rooms, a 170-person lecture hall with broadcast capabilities, a full service cafeteria, an office of the NASA Credit Union, a library, a travel office, a fitness center, and exterior terraces. Two artists were commissioned to provide a mural and floor design for the lobby.

We encourage members to visit the new facility. For information on the building, please contact Joseph Papa at (202) 334-3100.

Fifth German-American Frontiers of Engineering Symposium

Participants in the GAFOE 2002 Symposium.

The fifth German-American Frontiers of Engineering (GAFOE) Symposium was held at the National Academies Building in Washington, D.C., May 16–18, 2002. Modeled on the U.S. Frontiers of Engineering Symposium, this bilateral meeting brought together 60 engineers ages 30 to 45 from German and U.S. companies, universities, and government agencies and laboratories. NAE works with the Alexander von Humboldt Foundation to organize GAFOE symposia activities. NAE member **Sangtae Kim**, vice president and information officer, Lilly Research Laboratories, and Albert Weckenmann, professor, University of Erlangen-Nuremberg, cochaired the organizing committee and the symposium. The goal of the meeting was to bring together young leaders in a forum where they can learn about leading-edge developments in a range of engineering fields, thereby facilitating an interdisciplinary transfer of knowledge and methodologies. GAFOE has an added dimension of building cooperative networks across national boundaries.

The four topics covered at the meeting were: options for sustainable energy futures; tools for biomedical engineering; new trends in urban engineering; and intelligent transportation systems. Presentations, given by two Germans and two Americans in each of the four areas, covered a wide range of topics, including biomass energy, telemedicine, automated traffic-signal management, and the crash-avoidance car. Interesting and spirited discussions took place among the participants during the formal sessions and during breaks, receptions, and dinners. NAE member **Anita K. Jones**, Lawrence R. Quarles Professor of Engineering and Applied Science at the University of Virginia, gave the Thursday evening dinner speech. The group took a break from the plenary sessions on Friday afternoon for a tour of the National Air and Space Museum and other sites on the National Mall.

Funding for the symposium was provided by the U.S. Department of Energy, the Army Research Office, the Alexander von Humboldt Foundation, and the NAE Fund. Plans for the sixth GAFOE meeting to be held in Germany in 2003 are under way.

For more information, contact Janet Hunziker in the NAE Program Office at (202) 334-1571 or by e-mail at <*jhunzike@nae.edu*>.

Inventory of Public Awareness of Engineering Activities

NAE member **Stephen D. Bechtel, Jr.**, chaired an initiative to inventory current programs in the United States by professional societies, universities, foundations, science museums, television producers, and industry to increase the public understanding of engineering. The project is designed to help the engineering community maximize its resources to deliver a comprehensive, coordinated, sustained message to improve public awareness of the fundamental importance of engineering to the quality of life and to the productivity and economic strength of the nation. A questionnaire was developed and distributed to 628 organizations in November 2001; 245 responses were received. The inventory showed that the engineering community is devoting significant resources to public relations, education, and public affairs—on the order of $400 million annually. Many of these projects, however, do not have clear goals, consistent messages, or metrics for determining effectiveness. Indeed, evidence indicates that most programs have not been successful and should be reassessed and coordinated with other programs. NAE plans to work with a variety of groups in the engineering community to develop a coordinated plan for future activities.

For more information, contact NAE Executive Officer **Lance Davis** at (202) 334-3677 or by e-mail at <*ldavis@nae.edu*>.

NAE Fellow Addresses German Council on Foreign Relations

Recent statements by President Bush and other top administration officials have made it increasingly clear that the United States is in the process of adopting a more proactive policy in the war against terrorism. This was the focus of a statement by Raphael Perl, an NAE fellow and specialist in international terrorism policy, on July 2 before the German Council on Foreign Relations. Perl stressed that U.S. antiterrorism policy is changing from containment to preemption, from the limited retaliatory use of military force to the preemptive use of decisive military force, and from limited covert activity to enhanced covert action.

Perl warned that "preemptive action, and the threat thereof, is a potent policy tool" and that the challenge to U.S. and European policy makers "is to exercise such options wisely and to recognize which situations can be improved by use of preemptive action and which not." An added challenge, he said, is to ensure that preemptive action "does not result in nations being unnecessarily isolated from the coalition efforts we all seek to promote" (for the full text, see <*http://usinfo.state.gov/topical/pol/terror/02070204.htm*>).

Perl is study director for the NAE Committee on Combating Terrorism: Prioritizing Vulnerabilities and Developing Mitigation Strategies. The committee's report is expected to be released in early 2003.

Council and Staff Awards Luncheon

The National Academy of Engineering (NAE) recently held its annual Council and Staff Awards Luncheon in the Chesapeake Room of the Swissôtel, The Watergate. **President Wm. A. Wulf** hosted the ceremony.

Wm. A. Wulf and NAE Council Chair **George M.C. Fisher** presented copies of the Council Resolution and gifts to retiring council members **Tom Everhart**, **Julia Weertman**, and **Gene Wong** for their contributions during their years of service.

Two NAE Service Awards were presented to NAE staff members Kimberly West, public information assistant/assistant awards administrator, for five years of service, and Belinda Smith, Membership Office staff associate, for 30 years of service.

Staff Achievement Awards were also presented to Carol R. Arenberg, managing editor of *The Bridge* and other NAE publications, Penelope Gibbs, program associate, Greg Pearson, program officer, and Belinda Smith, Membership Office staff associate. All four received certificates of appreciation and cash awards.

NAE Fellows Program

Every year, NAE seeks a few talented people to become NAE Fellows. The Fellows Program was established in 1984 to give professionals in engineering and other fields an opportunity to broaden their exposure to and understanding of major technological and public policy issues facing the United States. NAE Fellows work directly with Academy members and other leaders in U.S. universities, industry, and government.

Most participants in the program have recently completed graduate degrees or are on temporary leave (e.g., sabbatical) from universities, government laboratories, or private companies. There are no formal prerequisites for candidates other than an intense curiosity about the interactions of technology and society; NAE generally seeks a "good fit" between a candidate's interests and expertise and current program activities.

Fellows typically assume responsibility for one major project during their tenure. For example, they may help conduct a consensus study, workshop, or symposium on a technology issue of national importance and prepare and disseminate the resulting publication. All Fellows develop close working relationships with NAE staff, NAE officers, and members of volunteer committees involved in specific projects. Fellows work under the direct supervision of the NAE Program Office.

NAE is currently seeking candidates with an interest and expertise in environment as it relates to energy, water, security, and international issues. The candidate may focus on the engineering, policy, and economic aspects of an issue or a broad global perspective of the subject.

Fellowships usually last from 12 to 24 months, although the term of tenure may be adjusted to meet the needs of the applicant. Stipends are based on the candidate's experience and present salary level. Universities, government laboratories, and private companies often provide a portion of support for individuals on leave from their institutions.

To apply for a fellowship, candidates should submit a vita and letter (no more than two pages) explaining how their interests align with current NAE program activities. For a description of current NAE programs, see the "NAE Program" in the left-hand menu of the NAE website at <*http://www.nae.edu*>. **Applications for fellowships beginning in winter 2002 or spring 2003 are due by October 15, 2002. Applications for fellowships beginning in summer or autumn 2003 are due by February 1, 2003.**

For further information, contact Dr. Jack Fritz in the NAE Program Office, 500 5th St. N.W., Washington, D.C., 20001, at (202) 334-2491, or by e-mail <*jfritz@nae.edu*>.

Gary Fanjiang Joins NAE as Fellow

Gary Fanjiang

Gary Fanjiang, M.D., M.B.A., joined NAE in July to help direct the Engineering the Delivery of Health Care Program. Dr. Fanjiang, a resident at the Tufts New England Medical Center and the Boston Floating Hospital for Children, is trained in pediatrics and psychiatry. A graduate of Cornell University and the Tufts University School of Medicine, Dr. Fanjiang also has an M.B.A. in health care management. He has worked at the Harvard Healthcare Delivery Center, a group that develops pioneering designs for health care systems, and was a founding team member of several health care Internet start-up companies. In addition, he has been a consultant in the biotechnology industry. He has extensive experience in medical research and has published several clinical guides.

Convocation of the Council of Academies of Engineering and Technological Sciences

In May 2003, NAE will host the Convocation of the Council of Academies of Engineering and Technological Sciences (CAETS) in Hollywood, California; the topic of the symposium this year will be the convergence of information technology and entertainment. The impact of information technology on entertainment is apparent everywhere, especially in the dazzling special effects in contemporary films and video games. The impact is far from one-sided, however. Increasingly, ways of telling a story and evoking emotional responses borrowed from the entertainment industry are being used for very serious purposes, such as training people who must make decisions under stress. The convocation symposium will explore interactions between these technologies, applications, and cultures.

CAETS is an international organization of academies of engineering. Leaders of member academies meet annually to discuss common problems with an international dimension, such as climate change, energy, and water and other scarce resources. The symposium is held biennially on a topic chosen by the host country. CAETS will mark its twenty-fifth anniversary at the 2003 meeting.

Elizabeth Hollenbeck, NAE Intern

Elizabeth Hollenbeck

Liz Hollenbeck is a master's candidate in mechanical engineering at the University of California, Irvine, where she plans to pursue her Ph.D. in the same subject. She was recently offered a NASA Fellowship from the Lyndon B. Johnson Space Center in Houston, Texas, for her work on optical microsystems. As a Christine Mirzayan Intern at NAE, she worked on the Engineer of 2020 Project.

Amanda Sarata, NAE Intern

Amanda Sarata

Summer intern Amanda Sarata worked on the Engineering and Health Care Systems Project. Amanda has a B.A. in biology from Carleton College, an M.S. in science and technology policy from the University of Minnesota, and is an M.P.H. candidate in public health genetics at the University of Washington. She worked for the senior policy advisor to the commissioner of health, Minnesota Department of Health, to develop a strategy for addressing issues of patient safety, which included preparing testimony for the Agency for Healthcare Research and Quality on a research agenda for patient safety from the state's perspective. She currently works with the Washington Genetics Task Force. In the future, she hopes to address the integration of new genetic technologies into public health policy.

Address by Dr. Eli Fromm on Receiving the Bernard M. Gordon Prize

Eli Fromm is the Roy A. Brothers University Professor at Drexel University.

Correction: In the summer issue, Dr. Eli Fromm was mistakenly identified as an NAE member. In addition, the text of his program summary was published instead of his acceptance remarks. The correct text is reprinted below. We deeply regret the errors.

President Wulf, Chairman Fisher, Dr. Good, Mr. and Mrs. Gordon, members of the academy, colleagues, family, and friends, it is difficult to find words to express the awe and humbled excitement I feel in receiving this wonderful honor. For an immigrant farm kid who was so poor that college seemed out of reach, standing here and receiving this crown jewel is more than I could ever have imagined; even more so because I am the inaugural recipient.

There are many people to thank for their part in bringing us here tonight—Mr. and Mrs. Gordon for their vision and generosity; members of the Academy, who, together with the Gordons, have had the wisdom and vision to recognize and highlight creative, entrepreneurial, and "out-of-the box" thinking as it pertains to the engineering educational enterprise. I thank you not only personally, but also on behalf of the entire community for bringing this issue to such a high level on the national agenda. Raising the consciousness and awareness of what has been accomplished leads to visions of what can yet be done. It is ultimately through this educational system that we will continue to provide the world with the creative talent that drives the economic engine and leads to the betterment of society and enriches the human condition. Thus, in the final analysis, the encouragement and stimulus you have rewarded and highlighted is a gift to us all.

There are many others to thank as well. No work encompassing the magnitude of change we have undertaken could have been accomplished without the creative and visionary contributions of many people. I have merely been the conductor of a multidisciplinary, geographically dispersed, and culturally diverse orchestra. To my many colleagues at Drexel who were involved in the early aspects of this work through the E4 program, and especially to the late Bob Quinn, I express great appreciation and a strong thank you for sharing the vision and being strong enough to cross traditional collegiate boundaries. As in the popular children's book, we were like the "little engine that could," and we became the kernel of something that has grown to be much greater. To my many colleagues in the Gateway Coalition I can only express my deepest thanks for sharing and shaping the vision and for contributing your creative talents to an expanded initiative dealing with a broad array of issues. To the visionary leadership at the National Science Foundation, our institutions, and several corporate sponsors, a warm thank you for providing the fuel that has fed the engine. I have learned much from working with so many talented people from such diverse institutional cultures. And, finally, thank you to my family, and especially to my wife of almost 40 years, Dorothy, who insists that I have given new definition to the phrase "I'll be leaving the office soon."

After 25 years of interdisciplinary research in biomedical instrumentation, miniature implantable or ingestible sensors and transmitters, I found myself in a position in the mid-1980s of taking a broad look at undergraduate engineering education. That look, and what followed, is what brought me here tonight.

From the 1950s through the 1980s, the model of our undergraduate educational enterprise had become increasingly analytic and fragmented into a large number of independent parts; at least they seemed independent to the student. There were some who wanted to add new technical subject matter continually, without losing sight of the fundamentals; others, and national reports, increasingly called for more well rounded graduates with the ability to function in the socially interactive, communicative business climate of modern industry. Exasperated educators simply said there was insufficient opportunity to "do it all."

We took that opportunity to consider a total restructuring and have evolved a model that does, indeed, enable us to do much more, be functionally more effective and time efficient, and address much broader issues than curriculum alone. In the model, engineering is the centerpiece, and relationships to the physical and social sciences are strengthened. The new structure also allows for the addition of new dimensions, so that the whole is greater than the sum of its formerly independent parts.

Engineering has been brought up front and integrated with the sciences, mathematics, humanities, and social sciences into a holistic experience. Integration also provides an opportunity to link the societal and historical perspectives while embedding the development of communication and organizational skills. The inversion also creates opportunities for new approaches in the upper division—to go into greater depth, to introduce technologies that are just on the horizon, or to create cross-institutional student/faculty teams, such as those that conduct concurrent engineering designs. Design, the essence of the creative process, has become a motivator and driver to using the tools of mathematics, the hard sciences, and the social sciences to create something new or better. Design motivates the higher order vision and creative thinking in our emerging engineering professionals. We merge synthesis with analysis, as well as the abstract, with societal-centered practice. This approach excites students, establishes a context for their studies, and gives them the opportunity to be creative and express a vision. In total, this approach creates a student-friendly, broad intellectual foundation for which the school of engineering takes leadership responsibility. With this restructuring, the professional discipline is now the centerpiece of the intellectual debate, without loss of the foundation; in addition, career-supportive issues that are equally applicable to any professional discipline are interwoven.

Beyond curricular content, faculty are examining educational methods and how we teach as well as what we teach. They are using technologies to make the educational process more effective and rewarding. Student professional development includes not only communication, interpersonal skills, and team-building skills, but also ethics and societal impact. These are built into an integrated program so they are dealt with in context and not as independent units of a disjointed program. Finally, our engineering faculty has defined succinct, measurable objectives and outcomes based on computerized student-response data collected, analyzed, and fed back for improvement. There is, indeed, a significant and sustainable cultural change taking place in engineering education, and it has been rewarding to witness it.

One contributor to that cultural change has been communications technologies, which has enabled our student and faculty connectivity. In the years ahead we expect even more global cross-institutional linkages and further integration in our educational programs, making them more exciting, rewarding, and, at the same time, more intensive technically and intellectually broader. As a result, our students will be better graduates, not only because of their access to far-flung facilities, but also because of the intellectual maturity and broader cultural understandings that come from such linkages. Much of that is, and will continue to be, technology enabled.

Beyond links across institutions nationally and internationally, envision, if you will, the day when a student (or a practicing engineer) will have sensory feedback at the keyboard while conducting a remote operation. The human senses can be important to the understanding of real operational characteristics of an experiment or development. Envision, if you will, the possibility of visual, touch, force, and maybe even olfactory sensory feedback from a remotely controlled engineering operation or product development. Or, think for a moment of a web repository, such as the one we are building, just one of many content seeds for a fabulous digital-library environment. Envision a student working with computer-based modules to develop solutions to an open-ended engineering problem. As he or she works through several scenarios, the names of important historical figures or events associated with the concepts, theories, and applications pop up. Now the student can digress for a moment and learn a bit about those individuals and periods. Furthermore, there is a chain of historical, social, or industrial events that preceded, coincided with, or followed each leader's work; each link has text, sound, and video to make the setting vivid. Imagine the wealth of knowledge and worldliness, as well as the technical understanding, this student will gain through such *self-driven* integration. The evolution of these tools will continue as the vision and imagination of our emerging engineering professionals are further stimulated.

Thank you again for this great honor and for sharing this evening with me.

Calendar of Meetings and Events

September 3–4	Engineering of 2020 Scenario Development Workshop Woods Hole, Massachusetts
September 10	Governing Board Executive Committee Meeting
September 19–21	U.S. Frontiers of Engineering Symposium Irvine, California
September 25	Charles Stark Draper Prize Committee Meeting
September 27	Committee on Engineering Education Meeting Irvine, California
October 4	Finance and Budget Committee Meeting NAE Council Meeting and Working Dinner
October 5	NAE Council Meeting Peer Committee Meetings
October 6–8	NAE Annual Meeting
October 9	Governing Board Executive Committee Meeting
October 24	Fritz J. and Dolores H. Russ Prize Committee Meeting
October 24–26	Japan America Frontiers of Engineering Symposium Tokyo, Japan
November 4	Engineer of 2020 Steering Committee Meeting Irvine, California
November 12	Governing Board Executive Committee Meeting
November 12–13	NRC Governing Board Meeting
December 6	Committee on Membership Dinner Meeting Irvine, California
December 7	Committee on Membership Meeting Irvine, California
December 10	Governing Board Executive Committee Meeting

All events are held in the Academies Building, Washington, D.C., unless otherwise noted.

In Memoriam

J. DONOVAN JACOBS, 91, retired chairman, Jacobs Associates, died on August 26, 2000. Mr. Jacobs was elected to NAE in 1969 for his invention of the tunnel sliding floor for rapid excavation, which greatly improved tunnel construction.

RICHARD C. JORDAN, 93, professor and head (emeritus), Department of Mechanical Engineering, University of Minnesota, died on June 14, 2002. Dr. Jordan was elected to NAE in 1975 for his pioneering research on energy conservation through climate control on solar energy and for his national and international leadership in engineering education.

YUEN TZE LO, 82, professor emeritus of electrical and computer engineering, University of Illinois at Urbana-Champaign, died on May 10, 2002. Dr. Lo was elected to NAE in 1986 for his inventions and innovative ideas that significantly advanced the theory and design of antennas and arrays.

DAVID W. McCALL, 73, retired director, Chemical Research Laboratory, Bell Laboratories, Lucent Technologies, died on June 6, 2002. Dr. McCall was elected to NAE in 1984 for his leadership in the engineering of polymers for high performance and reliability in communications and electronics.

HENRY M. PAYNTER, 78, professor of mechanical engineering (emeritus), Massachusetts Institute of Technology, died on June 14, 2002. Dr. Paynter was elected to NAE in 1997 for his contributions to the analysis, design, and control of complex multidisciplinary systems and for developing the Bond Graph modeling language.

LOUIS W. RIGGS, 79, retired chairman, Tudor Engineering Company, died on June 11, 2002. Mr. Riggs was elected to NAE in 1987 for his leadership and innovative design of bridges and rapid transit structures in the United States and other countries.

ALEXANDER R. TROIANO, 93, Republic Steel Professor (emeritus), Department of Metallurgy and Materials Science, Case Western Reserve University, died on June 12, 2002. Dr. Troiano was elected to NAE in 1986 for his distinguished contributions to the understanding of the mechanical behavior of metals and to the education of metallurgists.

National Research Council Update

Outside, Independent Reviews for Large-Scale Engineering Projects of the U.S. Army Corps of Engineers

After recent controversies about the assumptions and analyses used by the U.S. Army Corps of Engineers (USACE) for project proposals, especially a draft feasibility study of a $1 billion plan to enlarge locks on the Upper Mississippi River-Illinois Waterway, Congress requested that a study be conducted to determine when USACE should solicit independent reviews of its plans. *Review Procedures for Water Resources Planning*, a new report by a study committee of the National Research Council (NRC), concludes that external scientific reviews should be done of the most costly, complex, and controversial planning studies. The study committee recommends that the reviews be made available to the public and that the Corps respond in writing to each of the main points. "The highest degree of credibility will be achieved if responsibility for external review is given to an organization that is independent of the Corps," said committee chair and NAE member, **James K. Mitchell**.

The committee also recommends that the Army create a small professional staff to administer the Corps' review process and decide, on a case-by-case basis, whether a planning study merits external or internal review. Congress should also create a review advisory board to provide periodic advice to the project review group to ensure that reviews are consistent, thorough, and timely.

The committee recommends that Corps studies of projects that are expensive, very controversial, affect a large geographic area, or involve a high degree of environmental risk be reviewed by an independent organization. The role of all review panels, external and internal, should be to identify, evaluate, and comment on key assumptions that underlie the technical, economic, and environmental analyses in the planning studies. The chief of engineers, or district engineers in certain cases, should then, in writing, either agree with each key point and explain how it will be taken into account or rebut the comment and explain why it is being rejected. The review panels should highlight areas of disagreement that must be resolved by the White House and Congress, but they should not provide final approval or rejection of a project.

The committee also notes that reviews must be initiated early enough in the study process so that the results can be used to improve the study and lend credibility to the process. In complex and controversial planning studies, an initial review might be conducted early on and a more comprehensive one later. Reviews will generally represent a small fraction of the overall cost of major planning studies and might even lead to savings.

NAE member **James K. Mitchell**, Virginia Polytechnic Institute and State University, chaired the study committee. The full text of the report is available online at: *<http://www.nap.edu/catalog/10468.html>*.

Harnessing Science and Technology Capabilities to Fight Terrorism

A new report, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism*, concludes that the United States can take advantage of its scientific and engineering capabilities to detect, thwart, and respond to terrorist attacks. The report identifies actions that can be taken immediately, such as the deployment of available technologies, and acknowledges the urgent need to initiate research and development in critical areas. The study committee recommends that an independent homeland security institute be established to help the government make crucial technical decisions and devise strategies. "The scientific and engineering community is aware that it can make a critical contribution to protecting the nation from catastrophic terrorism," said NAE member **Lewis M. Branscomb**, cochair of the committee. "Our report gives the government a blueprint for using current technologies and creating new capabilities to reduce the likelihood of terrorist attacks and the severity of their consequences."

Actions that can be taken now to make the nation safer include: protecting and controlling nuclear weapons and nuclear material; producing sufficient supplies of vaccines and antibodies; securing shipping containers and power grids; and improving ventilation systems and emergency communications systems. Research should be pursued in a number of specific areas: intelligent, adaptive electric-power grids; reserving power for critical services, such as communication and transportation; and computer programs for data mining and information fusion; protective gear for rescue workers and sensors to alert them to radiological or chemical contamination and other hazards; improved design standards to make buildings more blast resistant and fire resistant; and air filtration and decontamination methods.

The committee recommends that the Office of Homeland Security, which is responsible for defining and coordinating a national counterterrorism strategy, establish a homeland security institute comprised of experts who can analyze vulnerabilities in critical infrastructures and evaluate the effectiveness of systems deployed to reduce them. The institute should be a not-for-profit, contractor-operated organization that can respond quickly to requests for advice from senior government officials.

The federal government will have to work closely with many other institutions, such as cities and states, private companies, and universities, to define and implement counterterrorism strategies. Many of the nation's critical infrastructures, such as transportation, communications, and energy systems, are privately owned and operated. To reduce the costs of security and sustain public commitment to counterterrorism efforts, and to make it easier for these companies to adopt new technologies, research should (as much as possible) be focused on technologies that not only protect infrastructures, but also deliver economic and social benefits to society.

The report was funded by the National Academies. NAE members on the Committee on Science and Technology for Countering Terrorism are **Lewis M. Branscomb** (cochair), Harvard University; **Richard L. Garwin**, IBM Thomas J. Watson Research Center; **Paul H. Gilbert**, Parsons Brinckerhoff International, Inc.; and **John L. Hennessy**, Stanford University. Prepublication copies are available online at: <*http://www.nap.edu/catalog/10415.html*> or from the National Academy Press, 1-800-624-6242.

Safety and Cost Consequences of Trucks on Interstates

According to *Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles*, a new report from the Transportation Research Board commissioned by the U.S. Department of Transportation, the federal government should monitor the effects on safety and road-maintenance costs of trucks that exceed federal weight limits operating on interstate highways. The report recommends that Congress charter a new federal organization to carry out pilot studies and research to determine the impact of trucks on highways, oversee the creation and evaluate the results of federal regulations, and recommend new regulations based on its findings.

Ninety percent of the costs of constructing and maintaining the interstate highway system is provided by the federal government, and current regulations are supposedly designed to limit wear and tear from heavy vehicles. Despite advances in technology and changes in traffic and highway conditions, federal truck regulations have only been significantly revised twice in the last 45 years. Because of concerns about competition in the freight industry, Congress has been deterred from taking up regulatory changes in this area.

The current federal limit for permits for truck operation is 80,000 pounds, and the standard tractor-trailer has five axles. The report recommends that states be allowed to issue permits for the operation of six-axle tractor-trailers weighing up to 90,000 pounds. The six-axle truck would reduce shipping costs moderately and cut down on pavement wear because of its lower weight-per-axle ratio. However, increasing the total weight of trucks would increase the costs of bridge construction and maintenance. The report also concludes that double trailers as long as 33 feet, trailers 5 feet longer than the common, 28-foot double trailers, should be permitted. The operation of double trailers and 90,000-pound tractor-trailers, however, should be up to the states and only operated by carriers with special permits.

Currently, no federal agency matches these activities and responsibilities. Therefore, the committee recommends that Congress charter an institute to monitor the new permit program, conduct pilot studies, and carry out basic research on the impacts of truck traffic. Based on its evaluations, the institute should recommend changes in federal regulations to Congress and the secretary of transportation. Objective data collection and analysis, coupled with full public comment, should help break the gridlock over size and weight policies.

The report also describes promising technologies for improving truck safety but concludes that more research and monitoring are needed before they can be commercialized and widely adopted. For example, an electronic braking system that could sense instabilities from sudden evasive maneuvers might improve a truck's ability to stop quickly and maintain control. The proposed pilot studies and permit program could provide incentives for industry and states to develop safety-related innovations.

NAE members on the committee were **James W. Poirot** (chair), CH2M Hill, Inc. (retired); **James E. Roberts**, California Department of Transportation; and **C. Michael Walton**, University of Texas, Austin. The full text is available online at: *<http://www.nap.edu/catalog/10382.html>*.

Publications of Interest

The following reports were recently published by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academy Press (NAP), 2101 Constitution Avenue, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at http://www.nap.edu or by phone at (800) 624-6242. *(Note: Prices are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Cybersecurity Today and Tomorrow: Pay Now or Pay Later. This report was assembled by the staff of the NRC Computer Science and Telecommunications Board from information in existing reports. Although the issue of computer and communications security has been examined many times from different perspectives, research results and recommendations have not been widely disseminated or adopted. The events of September 2001 demand that we revisit the issues of security and robustness in our infrastructures. This report brings the vulnerabilities into fresh focus and highlights approaches that could mitigate the risks. Paper, $12.00.

The Disposition Dilemma: Controlling the Release of Solid Materials from Nuclear Regulatory Commission-Licensed Facilities. At the request of the Nuclear Regulatory Commission, the National Research Council assesses the commission's decision-making processes with regard to the disposal of contaminated materials and recommends necessary changes. The study concludes that current processes are workable and protect public health but could be improved by a new framework that includes more input from stakeholders—including the general public—for developing and evaluating options for the disposal, reuse, and recycling of contaminated materials. The study committee's proposed framework, intended for use as a policy-making tool, incorporates the assessments of health, economic, and environmental impacts, among other factors. Paper, $49.75.

Learning from Our Buildings: A State-of-the-Practice Summary of Post-Occupancy Evaluation. Post-occupancy evaluation (POE), an evaluation of a building's performance once it is occupied and operational, is crucial to quality assurance. The downsizing of in-house facilities-engineering organizations, the increased outsourcing of design and construction functions, and the loss of in-house technical expertise have all increased the need for a reliable way of capturing and disseminating lessons learned. This report by the NRC Federal Facilities Council focuses on POEs and lessons-learned programs among federal agencies and in private, public, and academic organizations both here and abroad. The study points out how information gathered during POE processes can be used in the programming, budgeting, design, construction, and operational phases of facility acquisition. Paper, $31.00.

Safe on Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface. Although the chances that life exists on Mars are slim, NASA should use unmanned missions to identify zones of minimal biologic risk to humans by using organic carbon-detection techniques or by analyzing a Martian sample returned to Earth. At the same time, NASA should implement safeguards to protect Earth from potential contamination when missions return from space. This report outlines the environmental, chemical, and biological hazards NASA should assess before sending humans to Mars. Paper, $18.00.

Spills of Emulsified Fuels: Risks and Responses. There is a growing recognition of the potential hazards of surfactants that are widely used in household products and industrial applications. The study committee reviews current evaluation techniques of potential impacts from spills, especially the chronic environmental impacts. The committee also identifies other questions that must be addressed. Paper, $27.75.

We Need Your Help

To increase media coverage of engineering in general and NAE in particular, we are looking for stories about people that would interest the general public, stories that go behind the headlines to show how engineering adds a dimension to or provides a larger context for news of the day. Remember that visual appeal is always a plus. Please send your ideas to Randy Atkins, senior program officer for media/public relations, <*atkins@nae.edu*>, or call him at (202) 334-1508.