The mission of the National Academy of Engineering is to advance the well-being of the nation by promoting a vibrant engineering profession and by marshalling the expertise and insights of eminent engineers to provide independent advice to the federal government on matters involving engineering and technology.
A complete copy of The Bridge is available in PDF format at www.nae.edu/TheBridge. Some of the articles in this issue are also available as HTML documents and may contain links to related sources of information, multimedia files, or other content.
Editors’ Note

Why Engineering Ethics Matters
Deborah G. Johnson and Gerald E. Galloway, Jr.

Issue Dedication

Features

Ethics in Business: Every Employee’s Character and Behavior Count
Chad Holliday
All employees must think about how their work impacts society, the environment, and the safety of coworkers.

Protecting Dissent in Organizational Contexts
Thomas W. Smith III and Tara L. Hoke
Organizational culture must respect and facilitate dissent to ensure that engineering professionals comply with their ethical obligations.

Engineering Society Codes of Ethics: A Bird’s-Eye View
Arthur E. Schwartz
Engineering societies play a critical role in providing practical ethical guidance to engineers.

Engineering Codes of Ethics: Legal Protection for Engineers
Jeffrey H. Matsuura
Engineers can use codes of ethics to preserve their personal legal rights and reduce their risk of personal legal liability.

Beyond Protecting the Public from Risk
Robert B. Gilbert
Engineers can better serve the public by considering costs and benefits in addition to failure, and by working more closely with the public.

How Some Scientists and Engineers Contribute to Environmental Injustice
Kristin Shrader-Frechette
Flawed or misused analytic techniques for assessing pollution risk can allow environmental injustice, disproportionate health harm to children and to poor or minority communities.

Ethical Implications of Computational Modeling
Kenneth R. Fleischmann and William A. Wallace
Modelers must consider decisions from multiple perspectives, to take account of both their own values and those of their users.

(continued on next page)
52 Addressing Corruption in the Global Engineering/Construction Industry
William P. Henry
Corruption in engineering/construction is an important problem that national and international resources are available to combat.

59 Can Engineering Ethics Be Taught?
Deborah G. Johnson
Engineering ethics education increases the likelihood that engineering students will be prepared to handle ethical issues in their professional lives.

65 An Interview with . . .
Sal Khan, Founder, Khan Academy

72 News and Notes
72 Class of 2017 Elected
78 NAE Members Awarded 2016 National Medal of Freedom
79 NAE Newsmakers
81 Message from NAE Vice President Corale Brierley
84 National Academy of Engineering 2016 Donor Recognition
98 New Staff and Mirzayan Fellows Join Program Office
100 Calendar of Meetings and Events
100 In Memoriam

102 Publications of Interest

The National Academies of Sciences, Engineering, and Medicine

The National Academy of Sciences was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The National Academy of Engineering was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. C. D. Mote, Jr., is president.

The National Academy of Medicine (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the National Academies of Sciences, Engineering, and Medicine to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at www.national-academies.org
Editors’ Note

Deborah G. Johnson is Olsson Professor of Applied Ethics Emeritus, Department of Engineering and Society, University of Virginia.

Gerald E. Galloway, Jr. (NAE) is Glenn L. Martin Institute Professor of Engineering, University of Maryland, College Park.

Why Engineering Ethics Matters

As a profession that touches the lives and well-being of people, engineering has long considered itself to be guided by commonly held moral principles. These principles can be found in the examinations required of those seeking professional licensing, in the codes of conduct that shape and constrain engineering activities, and in the thinking and behavior of most engineers. Those who depend on and are affected by engineering expect (and are entitled to expect) engineers to behave in an ethical manner, and this is especially so when engineers engage in activities that have the potential for profound negative consequences.

One of the challenges for the engineering profession is to figure out how best to maintain these principles in a complex, diverse, and ever changing world. Those joining the engineering profession today are educated in colleges and universities and then socialized into the profession in the context of the organizational cultures they encounter as they move into practice and through their careers. Are educational institutions up to the task? Are organizations?

Throughout their careers, engineers are guided by rules, procedures, and precedents developed by the organizations in which they work and the professional organizations with which they associate. The manner in which these institutions and organizations deal with ethical issues, create an ethical climate, and provide models of ethical behavior have enormous influence on how engineers come to understand their professional roles and ethical responsibilities.

Over the last few decades the engineering community has taken steps to better address ethical issues and to establish a climate supportive of ethical behavior. The Accrediting Board for Engineering and Technology (ABET) and professional licensing organizations have included ethics education as a requirement on the path to graduation and professional preparation as well as a prerequisite in continuing professional development.

Recent decades have also been marked by the acceleration of technological development and innovation, and increasing recognition of the powerful role of technology in solving social problems. Unfortunately, the social impacts of rapid technological advances are not always carefully considered before they are implemented. Innovations in geoengineering, bioengineering, nanotechnologies, cyber systems, and artificial intelligence move society in directions not previously traveled, and the moral compass for the decisions that must be made may not be adequate for these new terrae incognitae.

The fact that engineers can build or manufacture something does not mean that the product or process necessarily will make an overall positive contribution to society. As the saying goes, “just because something can be done doesn’t mean it should be done.”

Most products, processes, and services affect different people differently. While cloud dusting might someday be able to shift the direction of a hurricane away from a coastal city, who should decide what areas must then take the brunt of the hurricane forces? Of course, engineers must have a role in such decisions, but should they be expected to make those judgments alone?

Notwithstanding today’s communication-rich environment, the challenges of communicating how a technologically complicated world works and how technological decisions are made are daunting. It...
is not always clear how to effectively carry messages about ethical issues to those who must deal with them. Whistleblowing has been a necessary but far from ideal method. Can a sounder foundation in ethics improve this situation?

Today, the public expects transparency. Engineers are expected to communicate information as to why and how they are carrying out their duties. But decisions are based on complex models of a situation, so it becomes increasingly more unrealistic to expect the public—and engineers—to understand what is inside the black boxes of models and software systems.

Engineering never takes place in a vacuum. Whether local, state, national, or global, engineering projects take place in a social context with historical, political, and economic patterns. The work of engineers affects and is affected by the social context. Are engineers responsible for ensuring that their projects and products do not exacerbate inequality among social groups? Can engineers just push this topic on to public decision makers or do they have a role in making these decisions with ethics in mind? As engineers operate around the globe, they may encounter unfamiliar social attitudes, expectations, and practices; how are they to react to actions considered legitimate in some societies and corrupt in others?

The articles in this issue address many of these questions and concerns. The authors have given a great deal of thought to various challenges in and approaches to engineering ethics, and, as experts in their area, provide their understanding. Although they bring key insights, in many cases they raise as many questions as they answer.

Building on the importance of trust, Chad Holliday makes the case for every company to ask how it can “move the dial from the majority of employees behaving ethically to all employees behaving ethically, day in and day out.” He explains the need to set the tone at the top and in an authentic way—employees know when it is empty talk. He also emphasizes the importance of both maintaining a corporate culture in which discussion of ethical issues is welcomed rather than suppressed and providing education related to ethics.

In harmony with Holliday, Thomas Smith and Tara Hoke focus on the importance of corporate cultures that facilitate expressions of dissent rather than suppressing them in favor of loyalty to management or the bottom line. A corporate culture in which dissent can be expressed allows issues to be addressed so that engineers can achieve their ethical obligations. The authors argue that “a culture in which discussions about risk are routine and questions are treated with respect and diligence will create a safer environment for communicating concerns.”

Engineering professional societies and their codes of ethics are especially important and are referenced many times in this issue. Arthur Schwartz puts the codes of ethics of professional societies in historical context and reviews a number of ethical issues relevant to engineering practice. In his conclusion, he states that engineers and engineering organizations “have an ongoing obligation to carefully review and recommend updates to their codes of ethics, in order to balance enduring ethical values and principles while addressing contemporary issues that affect the practice of engineering.”

The next article builds on the importance of professional society codes of ethics. Recognizing that when individual engineers sense an ethical challenge and consider raising a flag, they may be putting themselves at risk of pushback or even retaliation, Jeff Matsuura reviews steps to prepare for and protect against such eventualities. He explains that documenting the actions that have raised the ethical questions and following professional procedures and codes of ethics in raising ethical issues supports engineers in both making their case and protecting themselves.

Robert Gilbert avers that decisions about the safety of engineering projects or systems cannot be made solely by engineers. While absolute safety is normally unachievable, efforts to maximize safety and minimize risk often pit the high costs of achieving this goal against opportunities lost by “overspending” to achieve a goal that is not seen as necessary or desirable by the public. Such decisions must consider not only “normal” engineering approaches but also alternatives or more progressive design standards that address the risk tolerance of the public.

Kristin Shrader-Frechette argues that scientists and engineers contribute to environmental injustice insofar as they use flawed analytic techniques. She identifies three kinds of flaws: using nonrepresentative samples, misrepresenting uncertainty, and misusing statistical significance. She responds to those who would deny or excuse the unequal distribution of environmental risk, and persuasively concludes that “Sound science promotes sound ethics.”

Kenneth Fleischmann and William Wallace describe the various ways that values come into play in the pro-
cess of modeling and in the models themselves. Among the conclusions of their analysis that may be surprising to some (though perhaps obvious to self-aware modelers) is that the goal of building a model is not to be value neutral. Acknowledging that “no model of a natural system can completely, perfectly capture the complexity of reality,” the authors explain that the goal is “rather to be as transparent as possible about both the modeling process and the (known and potential) limitations of the model relative to reality.”

Corruption is the epitome of unethical behavior and engineering is not immune to it, perhaps especially in the construction industry. William Henry lays out the problems and many different kinds of corruption, and provides information about strategies and resources for countering it. He emphasizes the need to understand the terms used to refer to corrupt behavior so that engineers know it when they see it, can talk about it, and can take action to prevent it.

Given the ethical concerns discussed, engineering education faces a critical challenge in seeking to prepare student engineers for the ethical dimensions of their work. The final article takes on the skeptics who think engineering ethics can’t be taught. Engineering ethics education can help engineers to be ethical by providing knowledge of codes of ethics and standards of behavior, improving their abilities to recognize ethical issues, providing conceptual tools and practice in analyzing ethical issues and making ethical decisions, and motivating students to behave ethically.

The articles in this issue discuss a number of strategies for pursuing the ultimate goal expressed by Holliday, to achieve a point when all employees behave ethically, “day in and day out.” Whether it is ethics education, codes of conduct, awareness of corruption, or good science, ethical engineering is an ongoing endeavor involving most every aspect of engineering. These articles contribute to the endeavor, which requires the engagement, energy, insights, and actions of those who read them.

Acknowledgments

We are very grateful to Rachelle Hollander for suggesting that we collaborate on this issue. We had never met so the undertaking was somewhat risky but Rachelle’s judgment turned out to be prescient. We are also enormously grateful to Cameron Fletcher for her meticulous editing and her bountiful patience and professionalism.
This issue is dedicated to Vivian Weil and Caroline Whitbeck, two scholar pioneers and giants in the field of engineering ethics. Each contributed in unique and immeasurable ways to the foundation and development of the field. Rachelle Hollander, director of the NAE’s Center for Engineering Ethics and Society, describes their careers.

Two philosophers with strong connections to the NAE Center for Engineering Ethics and Society (CEES) and Online Ethics Center (OEC) passed away in 2016: Vivian Weil and Caroline Whitbeck. They are reckoned among the very distinguished in a small number of founders of the field of engineering ethics. They will be sorely missed by family, friends, and colleagues, but fondly remembered for their path-breaking achievements and vibrant personalities. Both were outstanding teachers, scholars, and mentors.

Vivian Weil

Vivian Weil, professor of ethics and director emerita of the Center for the Study of Ethics in the Professions at the Illinois Institute of Technology, passed away on May 7, 2016. She was a member of the IIT faculty for 44 years and a founding member and director of the center (1987–2014), which prospered under her leadership. She also served as director of the Ethics and Values Studies Program of the National Science Foundation in 1990–1991.

An influential advisor to the CEES and OEC, Weil made foundational contributions to scholarship and education about research ethics and engineering ethics and authored numerous publications in these areas. She worked on theoretical problems of human action and responsibility as well as practical issues of professional responsibility, primarily in engineering and science. Her interest in a wide range of issues and her ability to work with colleagues from numerous fields and backgrounds made her a valued contributor to many projects under the auspices of different societies and professional groups on such matters as publication ethics, intellectual property in graduate science education, conflicts of interest involving university scientists, educating scientists and engineers concerning professional responsibility, mentoring, and ethical issues in biotechnology.

She was a fellow of the American Association for the Advancement of Science (AAAS), a member of the governing board of the National Institute for Engineering Ethics (NIEE), and a founding member of the Association for Practical and Professional Ethics (APPE), where she chaired the executive committee for many years and served on editorial boards. In her work with APPE, she participated in all of the Graduate Research and Ethics Education summer workshops for graduate students in the sciences and engineering. Held from 1996 to 2002 with support from the National Science Foundation, the workshops allowed graduate students to work with faculty to develop case studies that are now available on the OEC, many of them with Weil commentaries.

Her affinity for promoting the engagement of philosophers with colleagues from other fields is illustrated in comments from postdoctoral fellow Julio Roberto Tuma, whom she mentored: “I met Vivian in the early aughts in what had to be the later part of her long and successful career at IIT. She had sent word to the Philosophy Department at the University of Chicago to see if there were any philosophers interested in a project that involved engineering application and involvement with philosophy. Knowing that I was interested in applying philosophy to real-world problems . . . , two of my advisors passed [along] her appeal, and I responded. Doing so changed both my career trajectory and my intellectual life as a philosopher.”

Weil received her AB and MA from the University of Chicago and her PhD from the University of Illinois, Chicago.

1 Her commentaries are available at www.onlineethics.org/Community/CommunityDirectory/VWeil.aspx#contactData.)
Caroline Whitbeck

Caroline Whitbeck, Emerita Elmer G. Beamer–Hubert H. Schneider Professor in Ethics at Case Western Reserve University and emerita professor of philosophy, passed away on September 5, 2016. She was a respected philosopher of science, technology, and medicine and founder of the OEC. She worked with former NAE president Wm. A. Wulf to arrange its transfer to the NAE and chaired the OEC Advisory Group (2007–2010 and 2011–2012). She spent much of her professional energy working with students and contributors to develop the OEC as an educational resource in the fields of engineering and scientific ethics. A quick search shows more than 150 contributions from her or citations about her on the site.

Whitbeck combined research and teaching interests in the philosophy of science, technology, engineering, and medicine, practical ethics, and feminist philosophy with interest in the education of a diverse student body for careers in engineering and the science-based professions. She made significant contributions to feminist philosophy and to medical ethics in the 1970s and 1980s, and in the 1980s and 1990s she developed the analogy between ethical and design problems, in particular problems of engineering design and research design. She pioneered active learning methods in the teaching of engineering ethics and the responsible conduct of research, especially methods that placed the learner in the position of the agent who must respond to the problem rather than a judge who evaluates responses that have already been constructed. Her book Ethics in Engineering Practice and Research was published by Cambridge University Press in 1998, and the second (revised) edition was released in 2011 with an entirely rewritten research ethics section.

Whitbeck greatly enhanced understanding of responsible research conduct in engineering and the physical sciences, including the Collaborative Institutional Training Initiative (CITI) module on authorship in engineering research and her article “Trust and the Future of Research” for Physics Today. She edited a 1995 issue of Science and Engineering Ethics on trustworthy research and a 2005 issue of the International Journal of Engineering Education on engineering ethics. She served on the advisory board of Professional Ethics and on the editorial board of Science and Engineering Ethics.

Whitbeck was elected a AAAS fellow for her work in engineering ethics, and was a Phi Beta Kappa Visiting Scholar in 1994–1995. She held a bachelor’s degree in mathematics from Wellesley College, a master’s degree from Boston University, and a PhD in philosophy from the Massachusetts Institute of Technology.
Chad Holliday (NAE) is chair of Royal Dutch Shell plc and former chair of the US National Academy of Engineering.

All employees must think about how their work impacts society, the environment, and the safety of coworkers.

Ethics in Business
Every Employee’s Character and Behavior Count

Chad Holliday

Nearly ten years ago, Emmanuel Mignot, a Shell employee, was driving on a highway in a developing country when he was pulled over by a policeman, allegedly for speeding. The policeman asked him to pay $10 to avoid an official fine. The sun was beating down, there was no one else around, and he had enough money in his wallet. But he refused.

This prompted the policeman to initiate a process, which involved Mignot appearing at a tribunal a few weeks later. He waited for his case to be called in a metal shed surrounded by wire fencing, with men accused of a range of crimes. Some urinated on the floor. Others hassled him for money and cigarettes. At the end of the day, he stood before a judge and was released because the policeman failed to show up to testify.

When Mignot told his friends about this experience, they questioned his actions, arguing that it would have been much easier to pay the bribe. But Mignot, who was driving a Shell-owned car, was proud of the way he had behaved. “I felt it was important to make a contribution—no matter how small—to stopping bribery,” he explained. “And although I was driving on a weekend, I represented Shell.”

1 Here and throughout, unless otherwise indicated, quotations are based on personal conversations or email communications.
Mignot demonstrated the highest ethical standards. By this I mean he showed an unwavering and uncompromising adherence to his company’s ethical principles, regardless of the situation or personal impact. This is what I consider the benchmark for all employees working for businesses throughout the world.

It’s no good simply having some ethical standards. Even organized crime has its own brand of values. Nor is it impressive to claim highly ethical standards, as this suggests there’s some wiggle room. Achieving the highest standards throughout a company is possible, but only if all employees act like Mignot did, and never yield when making an ethical decision.

**State of Play**

Companies that set the bar this high will be trusted by their employees, the public, customers, governments—the list goes on. This trust is the cornerstone of a healthy business model. If a company is trusted for its ethical standards, it will encourage the brightest minds to apply for jobs, for example. It will also give people confidence to invest. Essentially, trust feeds into a virtuous circle.

The progress made by businesses in recent decades suggests that this view is widely recognized. Think of the companywide codes of conduct that have been introduced all over the world. While these codes alone are far from enough, they have brought much more consistency of approach to businesses.

Yet despite the steps that have been taken, the highest ethical standards are not being adopted in all companies all the time. The 2015 Volkswagen emissions saga and the steps taken by Mitsubishi in 2016 to falsify fuel economy data, far from isolated incidents in the global business community, are some evidence of this. The consequence is that trust of businesses, and those who work for them, is low. A Gallup poll conducted in December 2015 shows that business executives are seen as less honest and ethical than many professions (figure 1). Only 17 percent of respondents rated their honesty and ethical standards as high or very high.

The last time Gallup looked into the perceived honesty and ethics of engineers was in 2012, when engineers got an honesty score of 70 percent, tying them with doctors in third place. It was much better than some previous scores for engineers, who got a rating of

---

**Honesty/Ethics in Professions**

Please tell me how you would rate the honesty and ethical standards of people in these different fields — very high, high, average, low or very low?

Dec. 2-6, 2015

<table>
<thead>
<tr>
<th>Profession</th>
<th>% Very High/High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nurses</td>
<td>85</td>
</tr>
<tr>
<td>Pharmacists</td>
<td>68</td>
</tr>
<tr>
<td>Medical doctors</td>
<td>67</td>
</tr>
<tr>
<td>High school teachers</td>
<td>60</td>
</tr>
<tr>
<td>Police officers</td>
<td>56</td>
</tr>
<tr>
<td>Clergy</td>
<td>45</td>
</tr>
<tr>
<td>Funeral directors</td>
<td>44</td>
</tr>
<tr>
<td>Accountants</td>
<td>39</td>
</tr>
<tr>
<td>Journalists</td>
<td>27</td>
</tr>
<tr>
<td>Bankers</td>
<td>25</td>
</tr>
<tr>
<td>Building contractors</td>
<td>25</td>
</tr>
<tr>
<td>Lawyers</td>
<td>21</td>
</tr>
<tr>
<td>Real estate agents</td>
<td>20</td>
</tr>
<tr>
<td>Labor union leaders</td>
<td>18</td>
</tr>
<tr>
<td>Business executives</td>
<td>17</td>
</tr>
<tr>
<td>Stockbrokers</td>
<td>13</td>
</tr>
<tr>
<td>Advertising practitioners</td>
<td>10</td>
</tr>
<tr>
<td>Car salespeople</td>
<td>8</td>
</tr>
<tr>
<td>Telemarketers</td>
<td>8</td>
</tr>
<tr>
<td>Members of Congress</td>
<td>8</td>
</tr>
<tr>
<td>Lobbyists</td>
<td>7</td>
</tr>
</tbody>
</table>

FIGURE 1 Gallup poll results on honesty/ethics in professions, December 2015. © 2016 Gallup, Inc. All rights reserved.
45 percent in both 1983 and 1991. These scores show that progress has been made. But not enough.

The research from Gallup confirms in my mind that the only way to boost trust is if every single person working for every single company has the highest ethical standards. So the pertinent question for all businesses is, How do they move the dial from the majority of employees behaving ethically to all employees behaving ethically, day in and day out?

In answering this question I will share examples of ethical practice from different companies, including Shell. I am in no way suggesting that Shell is a poster company when it comes to demonstrating ethical values. Shell has had its issues, notably overbooking its reserves just over a decade ago and the bribery matter Panalpina that resulted in a deferred prosecution agreement in 2010. Since then, the company has invested significant time and effort at all levels of the organization to improve its ethical standards and move from compliance to commitment in the heart and mind of each employee.

The only way to boost trust is if every single person working for every single company has the highest ethical standards.

While I will focus on what individual companies should do, it’s important to stress that companies must work together, not in isolation, to achieve the highest ethical standards. If an ethical company does some work with a partner or supplier that is unethical, this undermines its credibility.

Companies should ensure that they go into business with those that operate to the same ethical standards they have. This can be done, for example, through due diligence into the ethical performance of the company as well as its owners, audit rights to confirm that the company is operating in accordance with the agreed ethical standards, and the right to terminate the contract if that is not the case.

**Tone from the Top**

A business can ensure that all employees behave to the highest ethical standards only if its senior executives set an example. As the adage goes, what interests my boss, fascinates me. This point was emphasized by Andrew Fastow, the former chief financial officer of Enron who spent more than five years in prison for his part in the institutional accounting fraud that caused the company’s downfall. In an interview with the Association of Certified Fraud Examiners (Useem 2016), he said:

Culture starts at the top. But it doesn’t start at the top with pretty statements. Employees will see through empty rhetoric and will emulate the nature of top-management decision making. . . . A robust code of conduct can be emasculated by one action of the CEO or CFO.

Many cases support this point. In 1979, for example, James Burke, chief executive of Johnson & Johnson, challenged 20 senior managers about the merits of the company’s principles—titled *Our Credo*—which had been in existence for nearly a century. “If we’re not going to live by it, let’s tear it off the wall,” he said. There was a frank exchange of views, which resulted in the decision to keep the credo and use it as a moral compass for the company.\(^2\)

Three years later—when seven people died after taking a Johnson & Johnson painkiller, Tylenol, that had been laced with cyanide—the company’s response was swift, decisive, and correct. The company removed every bottle of capsules from shops in the United States and warned the public. A couple of months later, the product was relaunched in tamper-proof packaging.

The way the company acted has been heralded as an example of effective crisis management. But I believe its actions also reflected its ethical standards. Burke and his team were clear in their communication to the media and the public. And they did not wriggle free from their responsibilities to consumers, who had placed trust in them when buying Tylenol. Effectively, Burke acted in accordance with the company’s credo, which begins with the following statements: “We believe our first responsibility is to the doctors, nurses and patients, to mothers and fathers and all others who use our products and services. In meeting their needs everything we do must be of high quality.” Burke’s actions set the tone for how all employees should behave throughout the crisis.\(^2\)

2 The Johnson & Johnson credo is available at https://www.jnj.com/about-jnj/jnj-credo.
Burke led by example. In a very different way, so did Peter Sharpe, Shell’s executive vice president for wells. After the explosion on BP’s Deepwater Horizon oil rig in the Gulf of Mexico in 2010, Shell updated a key manual with the engineering lessons learned from this tragic accident. It was important to Sharpe that all of Shell’s 2,500 well engineers learned the fresh content, but he recognized that sending a blanket email with a hefty attachment was not the way forward.

So Sharpe sat down, along with the other senior managers in his department, and took an exam that tested their understanding of the updated manual. Shell’s principal technical engineer set and invigilated the exam, and posted the leadership team’s results on the company’s intranet. Once Sharpe and his team had passed, he said to all of Shell’s well engineers: “We’ve done it, now it’s your turn.” Shell’s view runs counter to the Dilbert comic strip (figure 2): if well engineers do not pass the necessary tests, they are out of the company.

Culture

One of the main responsibilities of leaders like Burke and Sharpe is to influence the overall culture of a company. Crucially, they must make sure, through their words and actions, that there is complete alignment between a company’s code of conduct and its culture. After all, as the Dutch athletics coach Charles van Commenee put it, “Nobody is going to jump higher if you lower the bar” (Kessel 2011).

This point is emphasized by the organizational psychologist Kilian Wawoe, who worked in human resources for a bank for a large part of his career. He observed that “there is a culture and there are rules. If these rules do not reflect the culture, rules are useless” ( Jacobs 2014).

In countless codes of conduct there are clear statements about whistleblowing and the actions employees should take if they come across improper behavior. But this counts for nothing if a company’s culture makes employees feel unable to report to a manager what they have seen.

It comes down to having a culture in which all ethical dilemmas can be discussed in an open and transparent way, without fear of reprisal. Ann Tenbrunsel, professor of business ethics at the University of Notre Dame, experienced a very different type of culture a few years ago. She was invited to speak with staff at a big business about the importance of ethics in organizations. But when a few employees caught wind of the fact that Tenbrunsel was going to point out so-called ethical blind spots in their sector, they immediately cancelled the talk.

Tenbrunsel, who has spent the past two decades looking at why good people make bad moral decisions in the workplace, says this action is indicative of a culture where there is little or no appetite to discuss potentially sensitive subjects. It is similar to a child putting his hands over his ears and screaming in an effort to ignore what’s going on around him.

The trait of looking the other way to avoid seeing unethical behavior is something Tenbrunsel has come across regularly during her research. “The vast majority of the time, it’s never as simple as one individual being unethical in an organization,” she explained. “It may start that way. But their actions perpetuate because people around them turn a blind eye—consciously or unconsciously.” A culture that encourages “motivated searching, versus motivated blindness,” she contends, would help stamp out this attitude.
As important as openness is, an ethical culture should extend much further. This gets to the heart of how ethics is interpreted. For me, business is about people, not just kit, molecules, technology, and suchlike.

The Shell General Business Principles\(^3\) lay out Shell’s core values as honesty, integrity, and respect for people. Ethical decisions grounded in those values must be at the core of all energy projects—from ensuring that there is no place for bribery to instilling a transparent culture.

But a company’s ethical culture is also about the way it behaves in each country where it does work. This means employees must think about how their work impacts society, the environment, and the safety of coworkers.

In Iraq, as with every other country where Shell works, the company’s commitment to operate in accordance with its Business Principles extends beyond how it operates in oil and gas fields to how it works alongside governments, local communities, and others affected by its projects.

One way Shell does this is through its partnership with the AMAR Charitable Foundation, formed to help address the need for emergency medical care among Iraqis living near Majnoon, one of the largest oil fields in the world. The partnership has set up healthcare projects, one of which involves a team of Women Health Volunteers conducting home visits. In 2015 Shell supported 64 such volunteers in Basrah, and they carried out more than 13,000 visits throughout the year.

**ETHICS IN EDUCATION**

What other steps can be taken to ensure that a broad interpretation of ethics is understood by employees? Schools and universities have a role in fostering in

---

\(^3\) These are available at www.shell.com/about-us/our-values.html.
students the importance of ethics in society. An ethics test even makes an impression on Calvin, the six-year-old boy who was the brainchild of the American cartoonist Bill Watterson (figure 3).

Bringing ethics into the classroom or lecture hall supports the following reasoning (paraphrased from C.S. Lewis): “Education without values, as useful as it is, seems rather to make man a more clever devil.” It also ensures that ethics is in the psyche of employees on their first day on the job.

This matters, especially for professions such as engineering where it might appear that day-to-day decisions are ethically neutral. But such a view ignores wider considerations, such as the impact of drilling for oil near a village.

“Universities have a significant role to play in instilling the idea that ethics is a central part of all problems engineers grapple with,” says John Baldari, a former engineer in the US Army and now a doctoral candidate at the University of Leeds. “This will help eradicate employees saying things like ‘This is only an engineering challenge’ or ‘Ethics are a compliance officer’s issue.’ Every aspect of a project should be every employee’s concern,” he argues.

There are many cases of great harm being caused when workers do not adhere to ethical principles. In May 2008, for example, more than 5,000 students died as a result of the magnitude 7.9 earthquake in China’s Sichuan province. Reports stated that schools crumpled because construction companies had ignored civil engineering standards.

The disaster is a reminder for all engineers of the potential consequences of their actions. Whether an employee is a civil, aeronautical, mechanical, electrical, computer, petroleum, or chemical engineer, the highest ethical standards must be upheld. It’s vital for schools and universities to play their part in reinforcing this point.

Of course, education in ethics should not stop when employees join companies. At Shell, for example, Robert Patterson, executive vice president for engineering, set up informal presentations on “design and engineering practices.” Modelled on TED talks, the idea is that engineers speak openly about dilemmas they have faced and how they addressed them. The talks, on subjects such as the installation of subsea equipment, are recorded and the videos shared in Shell’s engineering community. “They get to the heart of what it means to be a professional engineer,” explains Patterson:

Yes, you have to be technically competent and you need to have broad knowledge of the subject. But you must also ensure your work lives up to the highest possible ethical standards. You have to take account of the impact of what you do on everyone affected by a project, from the local community to the government.

Character Counts: Three Questions to Guide Behavior

If businesses fail to focus on each of these three elements—leading by example, culture, and education—then dubious ethical decisions will creep in. Even if it’s only a few employees in a company behaving unethically, the ramifications are potentially huge. But if companies do successfully address these areas, they stand a chance of being able to operate consistently to the highest ethical standards.

And the higher a company’s ethical standards, the more it is trusted. Around 20 years ago when working for DuPont, I was on a business trip to Southeast Asia. DuPont was about to announce a partnership with a company from the region. A few days before the deal, I paid a visit to the US ambassador. We were chatting with government officials and representatives from different companies when the ambassador lured me away, saying he wanted to show me some prize rosebushes.

When we arrived at a couple of scrawny-looking shrubs, it became clear the ambassador wanted an excuse to talk in private. He warned me about the unethical standards of the company I was about to sign a contract with. He sought me out because of his experiences working with DuPont over the previous decade, which made him trust me. I would never have received that forewarning if that trust was not there. After this conversation with the ambassador, I took the decision to pull DuPont out of the project.

Gaining trust like this comes from never yielding in the face of ethical dilemmas—no matter how small the issue seems. The consequences of doing so are potentially massive. Think of Emmanuel Mignot. If he had
paid the bribe to the policeman that Saturday morning, he may have broken local and international corruption laws. That one small action may have sparked a series of events that could have eroded trust in Shell’s ability to operate in the region.

You never know the consequences of seemingly inconsequential acts. This means that the character and behavior of every single employee working for a company count, more than anyone imagines.

Ultimately, it comes down to all employees asking themselves three questions:

1. Would I be happy with it if my actions were reported accurately in a newspaper?
2. Would I be proud of myself if I did something that my manager, an ethical individual, found out about?
3. Would I be proud if my family found out about what I had done?

If the answer is no to any of these questions, the response is simple—say and do the right thing.

Acknowledgments

I appreciate support from Thomas Baird, my Shell colleague, in developing this article and finding examples to illustrate the message.

References


Useem J. 2016. What was Volkswagen thinking? The Atlantic, January/February. Available at www.theatlantic.com/magazine/archive/2016/01/what-was-volkswagen-thinking/419127/.
Organizational culture must respect and facilitate dissent to ensure that engineering professionals comply with their ethical obligations.

Protecting Dissent in Organizational Contexts

Thomas W. Smith III and Tara L. Hoke

Engineers’ primary ethical obligation in the performance of their professional duties is to protect public health, safety, and welfare. This obligation is captured in the rules adopted by state licensing boards, echoed in the oaths of the Order of the Engineer and its Canadian corollary, and codified as Fundamental Canon 1 in the ethical codes of the American Society of Civil Engineers (ASCE) and many other engineering professional societies.

While most engineers understand and are committed to their ethical obligations, professional services are not performed in a vacuum—that is to say, it is not always possible to make decisions that serve the public good without the challenge of potentially competing influences. We explain these competing influences and use recent examples of US engineering disasters to illustrate specific lessons for corporate culture in support of ethical practice.

Tom Smith is executive director and Tara Hoke is general counsel, both at the American Society of Civil Engineers.

1 The Canadian “Calling of an Engineer” is a ceremonial ritual dating back to the 1920s, in which engineers take an oath to honor their ethical obligation to protect the public, and many wear a special ring as a symbol of that commitment. Fifty years later, American engineers decided to create their own version of this ritual; hence, the Order of the Engineer.

**Background**

In their practice, engineers are subject to a host of external and internal pressures—from clients, employers, or colleagues—to obtain a desired result, to contain costs or meet deadlines, to compete in the marketplace. Often these pressures are at odds with each other.

Not all stakeholders on a project are affected equally by engineering decisions, so engineers may often find themselves in the difficult position of providing faithful service to multiple parties with conflicting needs and expectations. Even service to the public good is not without consideration of competing interests, as the most worthwhile project may still involve some tradeoff between degree of safety and financial feasibility.

---

Even the most worthwhile project may involve some tradeoff between degree of safety and financial feasibility.

---

The public places enormous trust in the judgment of engineering professionals to study and mitigate the risks that can be addressed, to communicate those that cannot be eliminated, and to warn when risks are too great or should not be taken. When, as is commonly the case, engineers strike the proper balance between these dictates, they are capable of transforming the environment for the betterment of humanity. When they fail to find this balance, however, the results can be calamitous.

---

**Recent Examples**

The destruction of the space shuttles Challenger and Columbia in 1986 and 2003, the 2010 explosion and fire on the offshore drilling platform Deepwater Horizon, and the recall of 2.4 million GM vehicles in 2014 are a few of the most notorious recent examples of engineering failures. While the technical details differ greatly, these four cases share two crucial similarities:

1. Engineering professionals did not take actions sufficient to protect the lives and safety of individuals who were relying on their expert judgment.
2. A flawed corporate or organizational culture created the circumstances that allowed an ethical failure of that magnitude.

Analysis of these examples offers multiple lessons on the importance of maintaining a corporate or organizational culture that respects and facilitates dissent in order to ensure that engineering professionals comply with their ethical obligations.

---

**What Is Corporate Culture?**

Corporate culture can be defined as the values and beliefs implicit in an organization’s conduct of its activities. While stated mission and goals may be a factor in determining this conduct, corporate culture is more rooted in the organization’s practices than in its ideology, shaped by people’s perceptions of how the organization sets priorities and encourages or discourages certain types of behavior.

In the engineering setting, the desired corporate culture is one that rewards commitment to the highest standards of professional ethics. Workers at all levels feel empowered and motivated to raise questions, address problems, and make decisions that serve the corporation while preserving the public good.

If, on the other hand, the culture favors loyalty to management or the company alone, service to the financial bottom line, or an unwillingness to “make waves,” the result will be an environment that hinders or even discourages the prioritization of public health, safety, or welfare. This unhealthy corporate culture places engineers faced with an ethical dilemma in the burdensome and isolated position of deciding whether to dissent on ethical grounds or to remain silent about a potentially catastrophic consequence.

---

**How Can Corporate Culture Aid an Engineer’s Ethical Practice?**

**Clear, Written Policies and Procedures**

One lesson from recent examples of engineering failures is the need for clear, written policies and procedures that emphasize legal compliance, financial transparency, and attention to the safety and welfare of workers, customers, and the public at large.

In their report on the Deepwater Horizon disaster, investigators cited BP’s failure to establish clear safety protocols as a significant contributing factor in the explosion (National Commission 2011, p. 126):

Corporations understandably encourage cost-saving and efficiency. But given the dangers of deepwater drilling, companies involved must have in place strict policies requiring rigorous analysis and proof that less-costly
alternatives are in fact equally safe. If BP had any such policies in place, it does not appear that its Macondo team adhered to them. Unless companies create and enforce such policies, there is simply too great a risk that financial pressures will systematically bias decisionmaking in favor of time- and cost-savings.

While an ethical engineer should demand proper safety testing even in the absence of a clear organizational mandate, the existence of a written policy establishes a priority of safety checks and avoids placing the engineer in the potentially tricky position of advocating for increased cost and delay against an uncertain or unquantifiable risk.

**Organizational Backing and Enforcement**

Organizations must treat their policies as more than mere words by providing the organizational backing and enforcement to ensure that officers and employees alike comply.

The classic illustration of a disparity between policy and practice is the oft-cited Enron Code of Ethics, in which then CEO Kenneth Lay affirmed the duty of all Enron employees to conduct business “in accordance with all applicable laws and in a moral and honest manner”—only a year before the company collapsed under perhaps the business world’s most notorious example of institutionalized and willful corporate fraud.

Similarly, in its communications to investigators studying the 2003 Columbia disaster, the National Aeronautics and Space Administration (NASA) exposed a disconnect between its stated policies and the actual behaviors of its staff (Columbia 2003, p. 177):

NASA’s initial briefings to the Board on its safety programs espoused a risk-averse philosophy that empowered any employee to stop an operation at the mere glimmer of a problem. Unfortunately, NASA’s views of its safety culture in those briefings did not reflect reality.

Shuttle Program safety personnel failed to adequately assess anomalies and frequently accepted critical risks without qualitative or quantitative support, even when the tools to provide more comprehensive assessments were available.

If the culture of an organization is one that accepts corporate or management decisions without question, the pressures of conformity with existing norms will create added difficulties for engineers who wish to report or allay an ethical concern. Conversely, a culture in which discussions about risk are routine and questions are treated with respect and diligence will create a safer and more effective environment for communicating concerns.

---

**Communication failures have been recognized as a primary cause in many of the worst engineering disasters.**

---

**Open Channels of Communication**

Organizations need open channels of communication to ensure that critical information is conveyed to and received by the individuals best suited to address concerns, whether in management or in the field.

Communication failures have been recognized as a primary cause in many of the worst engineering disasters. In the Challenger accident report (Presidential Commission 1986, chapter V, “The Contributing Cause of the Accident”), for example, investigators noted a tendency of technical or management staff to avoid escalating problems to higher-level decision makers:

The Commission is troubled by what appears to be a propensity of management at Marshall [Space Flight Center] to contain potentially serious problems and to attempt to resolve them internally rather than communicate them forward. This tendency is altogether at odds with the need for Marshall to function as part of a system working toward successful flight missions, interfacing and communicating with the other parts of the system that work to the same end.

With Deepwater Horizon the most significant communication breakdown was a failure of technical experts to convey the importance of certain procedures down to the field-level staff charged with implementing them (National Commission 2011, p. 223):

Their management systems were marked by poor communications among BP, Transocean, and Halliburton employees regarding the risks associated with decisions being made. The decision making process on the rig was excessively compartmentalized, so individuals on the rig frequently made critical decisions without fully appreciating just how essential the decisions were to well

---

3 The Enron Code of Ethics is available at www.thesmokinggun.com/file/entons-code-ethics.
safety—singly and in combination. As a result, officials made a series of decisions that saved BP, Halliburton, and Transocean time and money—but without full appreciation of the associated risks.

A muddled line of communication may create both practical and motivational challenges to an ethical engineer. The engineer might believe s/he had received or sent communications to the correct parties when in fact this was not the case—or the engineer might believe it is futile to communicate an ethical concern because no one is listening.

Also, the ease of communication may itself send a message about priorities. If a team assigned to monitor safety is buried under several layers of hierarchy below the true decision makers, this may be read as a signal that safety concerns are not as important as other considerations.

Personal Accountability

Organizations must impress upon their workers the need to accept personal accountability for protecting the public good.

The independent investigator’s review of the GM recall cited the failure of any one person or entity to take responsibility for investigating the ignition switch failures as a major issue (Valuks 2014, p. 255):

A cultural issue repeatedly described to us and borne out by the evidence is a proliferation of committees and a lack of accountability. . . . One witness described the GM phenomenon of avoiding responsibility as the “GM salute,” a crossing of the arms and pointing out toward others, indicating that the responsibility belongs to someone else, not me.

Particularly in cases where a potential issue is inadequately understood or unquantified, a healthy corporate culture inspires each person to take initiative and assume an active role in resolving ethical concerns, even if that role is not expressly included in the individual’s assignment of duties.

Protection from Reprisal

The organization must create an environment where workers can voice questions or concerns without fear of reprisal. An underlying factor in the failure cases examined in this article was a cultural norm of silence on ethical or safety-related matters:

From the GM recall report (Valuks 2014, pp. 252–253): “Some witnesses provided examples where culture, atmosphere, and the response of supervisors may have discouraged individuals from raising safety concerns, including . . . supervisors warning employees to ‘never put anything above the company’ and ‘never put the company at risk.’”

From the Columbia report (Columbia 2003, p. 138): “When workers are asked to find days of margin, they work furiously to do so and are praised for each extra day they find. But those same people (and this same culture) have difficulty admitting that something ‘can’t’ or ‘shouldn’t’ be done, that the margin has been cut too much, or that resources are being stretched too thin. No one at NASA wants to be the one to stand up and say, ‘We can’t make that date.’”

From the Deepwater Horizon report (National Commission 2011, p. 224): “A survey of the Transocean crew regarding ‘safety management and safety culture’ on the Deepwater Horizon conducted just a few weeks before the accident hints at the organizational roots of the problem. . . . Some 46 percent of crew members surveyed felt that some of the workforce feared reprisals for reporting unsafe situations.”

Though protection from reprisal invokes the concept of whistleblower protection, this aspect of a healthy corporate culture cannot be addressed simply by adopting an antiretaliation policy. Instead, the culture must first encourage and assist employees in raising concerns or offering dissenting opinions, and then reward those who participate in resolving safety or other ethical issues.

The ideal corporate culture is one that does not find it necessary to protect whistleblowers at all, because problems of safety or other ethical concerns are addressed openly and in the early stages, without the need for drastic intervention.

Other Impacts of Corporate Culture

Impacts of corporate culture have been identified as a factor in ethical challenges other than safety-related failures.
Accountability, communication, and prioritization of safety concerns were identified as issues in post-Katrina assessments of the New Orleans levee system (ASCE 2007), demonstrating the need to establish a culture of safety in complex, multiorganizational engineering projects. In efforts to combat corruption in the global market, corporate culture has also been identified as a key element for preventing ethical and legal lapses (US DOJ 2012).

Moreover, although the examples discussed in this article represent extreme cases of the impacts of problematic corporate culture, it is important to recognize that corporate culture has an important role in the day-to-day life of all engineering professionals. Every engineer, regardless of role, experiences pressure from employers, clients, competitors, regulators, or the public at large—and the environment in which engineers face that pressure can have a significant positive or negative influence on their ability to adhere to the profession’s ethical standards.

In fact, an examination of cases reviewed by ASCE’s Committee on Professional Conduct, which enforces ASCE’s Code of Ethics, reveals that a faulty corporate or organizational culture was frequently a contributing factor in an engineer’s ethical misstep. These include cases in which engineers plagiarized reports, conspired to make illegal political contributions, overbilled a public agency, colluded on bid submissions, or fraudulently altered an approved set of design plans (ASCE 2005, 2006, 2009, 2014, 2016).

Commitment to Corporate Culture

Extraordinary courage may be required for an engineer to speak out in an environment that operates to silence dissent. It is therefore important to train engineering professionals collectively to build ethics into their corporate culture—creating a framework in which dissent on matters of ethical concern does not rely on extraordinary behavior but rather can be offered at comparatively low personal risk.

Creating such an ethical corporate culture requires active commitment at all levels of an organization. Managers must set the tone for their departments, involving other staff members in decisions, being receptive to questions or criticism, and carrying the message of safety and ethics to all who report to them. Junior-level staff should be expected and encouraged to learn and expand their understanding of their professional responsibilities by studying applicable laws, corporate policies and guidelines, and ethical codes of conduct. Training and resources should be regularly made available for employees at all levels.

But even the most diligent managers and the most knowledgeable junior staff members cannot create an ethical culture without a wholehearted commitment to professional ethics by those at the top. The organization’s leadership has the greatest responsibility for establishing an ethical culture, as clearly stated by the Deepwater Horizon commission (National Commission 2011, p. 218):

[E]ven the most inherently risky industry can be made much safer, given the right incentives and disciplined systems, sustained by committed leadership and effective training. The critical common element is an unwavering commitment to safety at the top of an organization: the CEO and board of directors must create the culture and establish the conditions under which everyone in a company shares responsibility for maintaining a relentless focus on preventing accidents.

Extraordinary courage may be required for an engineer to speak out in an environment that operates to silence dissent.

Engineering and corporate leaders must first “talk the talk,” by setting clear policies grounded in ethical standards, communicating a consistent message about ethical expectations, and offering training and resources to drive compliance at all levels. Next, they must also “walk the walk,” by holding every person accountable for compliance with ethical standards, ensuring that organizational incentives and disincentives align with the desired behaviors, being open and transparent about decision making, and above all providing a model of ethical behavior through their own actions.

Addendum

ASCE provides an array of ethics resources for engineering leaders, practitioners, and students. They include seminars, webinars, and publications on engineering ethics, and ethics sessions at ASCE’s technical
meetings. In addition, ASCE hosts regular Order of the Engineer ceremonies and publishes a monthly column titled “A Question of Ethics” (www.asce.org/a-question-of-ethics), featuring engineering ethics case studies and current topics.

**References**


Engineering societies play a critical role in providing practical ethical guidance to engineers.

Engineering Society Codes of Ethics
A Bird’s-Eye View

Arthur E. Schwartz

Engineering societies play a vital role in the field of engineering ethics. Convening meetings, developing seminars and educational events, publishing resources, providing continuing education, and highlighting important developments in the field are just some of their many activities to improve professional and public understanding of the ethical challenges faced by engineers. The programs and activities spring from the values and principles expressed in each society’s code of ethics, which is a starting point for any discussion of engineering ethics in the United States and beyond.

Engineering Codes of Ethics: Background

Historic Foundation

As the technical disciplines of engineering emerged and expanded in the 19th century, engineering societies and their members recognized the need for practicing engineers to be guided by basic principles of appropriate conduct in their professional practice and relationships with employers, clients, other engineers, and, most importantly, the public.

The engineering profession’s organizational structure began to take shape with the onset of the Industrial Age and ensuing growth of scientific and technical skill and knowledge. The American Society of Civil Engineers (founded in 1852), American Institute of Mining, Metallurgical and Petroleum Engineers (1873), American Society of Mechanical Engineers...
(1880), Institute for Electrical and Electronics Engineers (1884), and American Institute of Chemical Engineers (1908) each focused on their field’s technical core but also began to explore its ethical dimensions, with some developing basic canons or codes of ethics.

With the establishment in 1934 of the National Society of Professional Engineers came efforts to develop an overarching, multidisciplinary, common, and consistent code of ethics for all practicing engineers. Other practice-based engineering and technical societies also developed codes of ethics to reflect unique professional customs, practices, and concerns.

Structure and Enforcement
The most important ethical obligations typically appear at the beginning of each society’s code. The structure and enforcement provisions of engineering and technical society codes of ethics vary. Some organizations have lengthy codes with detailed canons, principles, rules, and interpretive commentary, while others provide only brief statements of general philosophical positions. And while some codes are aspirational and intended as general guidance, others stipulate consequences, with disciplinary penalties for violations.

Content
While there are significant similarities among the many codes of ethics of US engineering and technical societies, there are also important differences in what the codes address and do not address. For example, all but a handful of societies have statements explicitly addressing disclosure of concerns to authorities, whereas only about half include a code or any kind of statement concerning discrimination or harassment, and about a third provide guidance on sustainability and/or the environment.

Adaptation and Updating
Engineering society codes of ethics are continuously refined, updated, and influenced by ongoing professional practice issues as well as changing ethical and moral attitudes.

Modifications include the removal of prohibitions and restrictions on advertising and other promotional activities, and the addition of guidelines on the provision of price information on services, environmental sustainability, collective bargaining, supplanting (i.e., one engineer replacing another in his relationship with a client without the supplanted engineer’s knowledge or consent), and professional development.

The following sections review key common areas of engineering society codes of ethics.

Primum Inter Pares: Public Health, Safety, and Welfare
The engineer’s role in protecting public health and safety is regarded in most codes as the most fundamental obligation. Engineers are expected to have a very high regard for the public good, although the language varies somewhat. Codes call on engineers to “have proper regard,” consider public health and safety a “fundamental concern,” “accept responsibility for the public health and safety,” “be cognizant that their first and foremost responsibility is to the public welfare,” and “accept responsibility in making decisions consistent with the safety, health, and welfare of the public.”

Notwithstanding the variations, it is clear that—unlike other professionals, such as attorneys, physicians, or members of the clergy, who owe their primary obligation to their client, patient, or the laity—the engineer’s principal responsibility is to the health, safety, and welfare of the public. This duty may at times create a serious conflict (or at a minimum disharmony) with the engineer’s concomitant obligation to the employer’s or client’s interests, putting the engineer in a difficult, sometimes untenable position. Engineers may find themselves under significant internal (personal) and/or external pressure and strain as they seek to address a public health and safety issue encountered in their professional practice.

Duty to Employer or Client
Many codes refer to the obligation of the engineer to act as a “faithful agent or trustee.” This language does

1 Some codes also include “fellow workers.”
not imply blind obedience to the employer or client but instead conveys an obligation to be direct, open, and clear and to act for the benefit of the employer or client, balanced with other ethical obligations such as the protection of public health, safety, and welfare.

**Disclosure of Concerns to Clients**

Most professional society codes of ethics recognize the engineer’s obligation to advise the employer or client of concerns discovered by the engineer in connection with his or her work.

Such concerns may arise when a project is not successful (i.e., it does not meet the needs and requirements of the client and the public), the cost of the project varies from what was originally estimated, or the engineer observes improprieties on the part of other consultants, contractors, or public officials. Problems that must be disclosed include violations of local building or construction code or of federal health and safety or environmental law, and financial improprieties such as fraud, embezzlement, or bribery.

Sometimes disclosure raises ethical challenges for engineers, particularly when an employer or client has sought to restrict such disclosures through confidentiality agreements or other mechanisms. However, when the information to be disclosed involves a serious violation of law or a danger to the public, employer- or client-imposed restrictions cannot stand in the way of the engineer’s obligation to communicate his or her concerns to appropriate parties or authorities.

Another challenge is the overruling of an engineer’s judgment by an individual who does not possess the technical competence to render a knowledgeable opinion. The vast majority of engineers work in industry and government and many are managed and even supervised by individuals who lack engineering (or any technical) education, experience, qualifications, or training. As a result, engineers sometimes find that their recommendations—based on sound engineering principles and judgment—are not accepted by their managers or supervisors. If an engineer believes that the failure to follow those recommendations will endanger public health, safety, or welfare, the engineer has an ethical obligation to seek appropriate resolution.

**Disclosure of Concerns to Authorities**

Many engineering codes of ethics have provisions about the engineer’s obligation to formally disclose concerns to appropriate authorities, such as government agencies and similar entities. (However, the vagueness of the term “appropriate authorities,” which appears in many engineering codes of ethics, is itself a challenge, as it does not provide clear guidance about the appropriate agencies to which the engineer should report.)

Even if reporting to the employer or client does not result in satisfactory action or follow-up by appropriate authorities to address the engineer’s concerns, it is generally recognized that the engineer has fulfilled his or her ethical obligation by reporting to the appropriate authorities.

In all cases, the engineer should cooperate and provide all necessary information to the appropriate authorities and government agencies.

**Competency**

Professional, technical competence is a critical ethical obligation and, of course, central to an engineer’s performance. Engineering involves numerous technical disciplines and subdisciplines and no engineer can be competent in all. Engineers must therefore know the scope and limitations of their competence and not practice beyond them.

---

**Employer- or client-imposed restrictions cannot stand in the way of the engineer’s obligation to communicate concerns to appropriate authorities.**

---

Furthermore, technical disciplines and subdisciplines often overlap and the line between them is murky and difficult to define. Engineers must recognize when to exercise professional self-restraint, acknowledging that they do not always possess the competence to perform certain activities or tasks. Under certain circumstances, an engineer who lacks competence in a particular area may be required to seek additional education, training, or experience in order to perform certain engineering services.

At the same time, engineers are expected to expand their professional knowledge through ongoing practice
and education, so a healthy tension exists between the obligations to practice within one's areas of competency and to enhance and update knowledge and skills.

The obligation to perform competently also places a responsibility on engineers who manage other engineers. They must be certain that the latter are appropriately assigned and managed to perform engineering services consistent with their competency for the protection of public health and safety.

Because the practice of engineering sometimes overlaps with other professions (e.g., architecture, landscape architecture, surveying, law), engineers have an ethical obligation to understand the laws and regulations relating to competencies required to practice in these areas as well as any limitations, restrictions, or prohibitions on coterminous professional practice.

Engineers must be sensitive to any appearance of impropriety, which could reflect poorly on the engineer and the engineering profession generally.

Signing and Sealing of Plans

Licensed professional engineers in the United States have special legal and regulatory duties and responsibilities under state law regarding their preparation, review, and approval of engineering documents (drawings, plans, specifications, reports submitted to clients or public authorities). They must not affix their signature or seal to any engineering plan or document that deals with subject matter in which they lack competence. Such work must be performed under the professional engineer's "responsible charge"—either the engineer who signs and seals the work or a competent subordinate who reports directly to and is supervised by the engineer signing and sealing the work. Failure to meet these duties and responsibilities can result in the loss of an engineer's license as well as disciplinary action (e.g., suspension or expulsion from membership) by the engineer's professional society.

Overarching Ethical Standards

Conflicts of Interest

Engineers, particularly those who work as consultants, sometimes perform work on behalf of parties in both the public and private sectors with different interests in connection with a project, transaction, or other business relationship. These professional relationships may raise the question of conflicts of interest.

Engineering codes of ethics originally prohibited engineers from becoming involved in any situation that involved a conflict of interest. However, because engineers often cannot avoid such situations, many codes were modified to instead require the engineer to disclose all circumstances relating to the conflict of interest. It is then generally up to the client to determine whether it is appropriate for the engineer to continue with the professional engagement, consistent with the law.

In all cases, following disclosure, even if all affected parties assent to the engineer's continued involvement, engineers must be sensitive to any appearance of impropriety, which could easily reflect poorly on the engineer and/or the engineering profession generally.

Confidentiality

Engineers in all areas of professional practice frequently become privy to information that is intended by the employer or client to remain confidential. It may be sensitive employer or client information, trade secrets, technical processes, or business information that, if disclosed or used improperly, could damage the business or other interests of the employer or client. Engineers are expected to demonstrate a professional level of care and loyalty in the performance of their services, and obligated to maintain an employer's or client's confidences—they must not disclose information to third parties without permission or consent obtained in advance. There are some exceptions, but as a general rule engineers who breach this obligation violate their ethical duty and may be subject to reprimand by their professional society.

Objectivity, Honesty, and Truthfulness

Objectivity, honesty, and truthfulness with employers, clients, and others are critical for establishing and maintaining the credibility necessary to practice effectively.

Unlike attorneys, engineers are not advocates or "hired guns" retained to marshal arguments in support of a position. Engineers are expected to be objective, honest, factual, and truthful in their reports, studies,
analyses, designs, assessments, feasibility papers, and related documents as well as public or private statements, public testimony, promotional efforts, and other communications and representations, both express and implied. Failure to adhere to these values and practices can have grave consequences and damage the reputation of the engineer, those with whom the engineer is associated, and the engineering profession generally.

**Engineers and the Law**

**Gifts, Bribery, and Violation of the Law**

No profession can maintain public trust if its members fail to meet minimum legal requirements. All engineers must follow criminal and civil laws to ensure their professional integrity and protect the public interest.

Engineers in both the public and private sectors may have contact with vendors, material suppliers, contractors, and other commercial parties who offer gifts of substantial value in connection with existing or anticipated contracts. Similarly, engineers who are retained or being considered for a project sometimes offer gifts of substantial value to public or private parties in connection with existing or anticipated contracts. Both practices violate professional society codes of ethics.

With the increase in global engineering practice, US engineers practicing abroad are likely to encounter varying ethical cultures and must navigate differing customs. At one time, the so-called “when in Rome . . .” rule prevailed as engineers and engineering firms followed local practice—for example, offering gifts and other remuneration in exchange for contracts. However, since the enactment of the Foreign Corrupt Practices Act (1977) and Organization for Economic Cooperation and Development (OECD) standards, US engineering firms are now legally required to follow all federal anti-bribery and related laws when performing engineering and related services abroad.

**Discrimination and Harassment**

Engineers have an obligation to be fair and just in their professional relationships and must avoid any action that treats others in a biased manner. In addition to violating code of ethics provisions, such conduct could result in legal and other sanctions against engineers and their employers that may reflect poorly on other engineers and on the engineering profession.

Many engineering societies address these issues in their professional policies and other guidelines rather than in their codes of ethics.

**Sustainability/Environment**

With the growth of interest in the environment and sustainable development in the United States and around the world, many engineering codes of ethics have supplemented or added language to address these issues.

Engineers, whose technical expertise and practice affect and shape the environment, are expected to use their skills to preserve and protect natural resources. Only a few codes do not address this issue specifically, instead taking the position that protection of the environment is included in or implied by more general code obligations to public health and safety.

---

**US engineers practicing abroad are likely to encounter varying ethical cultures and must navigate differing expectations.**

Some engineering societies that take enforcement action against members who violate other code provisions express the view that, while it is important to have sustainability provisions in their code of ethics, it may be difficult to effectively enforce them, or that such provisions could elevate the legal standard to which engineers are held and thus increase liability exposure. These societies are therefore reluctant to include such provisions in their codes of ethics.

**Expert Witness Testimony**

Engineers may be called upon to assist in the resolution of legal and other disputes between parties in litigation or to testify before other public authorities. Engineers serving in this role are expected to be objective, honest, factual, and truthful and to incorporate all pertinent
information in their reports, studies, analyses, designs, assessments, feasibility papers, statements, testimony, and related documents. As expert witnesses they should express an engineering opinion only when it is founded on knowledge of the facts, technical competence, and honest conviction.

**Conclusion**

Engineers and engineering and technical societies have an ongoing obligation to carefully review and recommend updates to their codes of ethics, in order to balance enduring ethical values and principles while addressing contemporary issues that affect the practice of engineering.

In the years ahead engineers can be expected to play an increasingly important role in global issues. Climate change, sea level rise, access to potable water, sustainable energy, food security, and the enormous worldwide growth in urban populations will present significant ethical challenges for engineers. Engineering professional and technical societies can provide ethical guidance to assist their members in addressing these crucial challenges.
Engineers can use codes of ethics to preserve their personal legal rights and reduce their risk of personal legal liability.

In cases involving corporate misconduct, senior management may attempt to blame engineering staff for product or service defects or failures.

In the Volkswagen emission testing scandal, for example, at various times during the company investigation Volkswagen executives suggested that engineering staff were largely responsible for the problem (AP 2015; Connett 2015). Those claims left the engineers involved vulnerable to termination of employment and legal claims raised by Volkswagen, by government authorities, and by individual consumers harmed by the scandal.

Volkswagen management, in effect, attempted to make company engineers scapegoats for this major corporate scandal. If engineers had created a written record using codes of ethics to document their concerns and objections, that record could have been used to rebut such unfair corporate allegations and to defend themselves from legal liability.

This article is written purely for educational purposes, solely to inform engineering professionals how codes of ethics can help them preserve and express their personal legal rights and reduce their risk of personal legal liability. It is also intended to encourage professional engineering organizations to recognize and consider the defensive use of their codes of ethics as they establish and modify them. If those organizations appreciate the potential defensive value of their codes for their members, they will exercise appropriate care to ensure that the codes provide an effective tool for assisting
engineers to protect themselves from liability and to exercise the full range of their legal rights.

Professional engineering societies should consider participating in litigation in which their members appropriately exercise their legal obligation to adhere to the terms of the society's codes of ethics. By providing expert testimony and filing briefs in support of members, the organizations will both encourage engineers to honor and respect the codes of ethics and enhance the overall beneficial impact and value of those codes.

Keeping a Written Record

If asked or ordered by an employer or client to engage in conduct an engineer believes in good faith to be suspect, the engineer should immediately consult codes of ethics and professional responsibility for the leading professional organizations in his or her engineering field. Some codes require an engineer to communicate ethical concerns directly to the employer or client.

Engineers should express ethical concerns in writing, specifically referencing applicable code provisions.

If a code bars or discourages the conduct and requires the engineer to communicate ethical concerns to the employer or client, the engineer should express the ethical concerns in writing, specifically referencing the applicable code provisions. Copies of this written expression of concern and code of ethics reference should be provided to the person who ordered the action and to appropriate human resources department staff. The engineer should also retain a copy of the document in his or her off-site personal records. If there has been a mistake or misunderstanding, this action will likely force clarification. If the order stands even after the written expression of concern, then the engineer has begun to establish documentation of both his or her concern and the basis for that concern in the code of ethics.

Written records describing concerns and objections and referencing specific code prohibitions and cautions help the engineer present a defense if claims of insubordination, malicious conduct, or failure to perform are raised by an employer or client. Such records also provide evidence of the engineer’s efforts to obtain “whistleblower” status, and the legal protections associated with that status, if the engineer chooses to raise the concerns with appropriate government authorities.

Whistleblower Protection

The federal government and 17 states provide protection for individuals qualifying as whistleblowers (NCSL 2010). A whistleblower is an individual who alerts appropriate legal authorities about behavior that the individual reasonably believes to be illegal or fraudulent. In some jurisdictions, whistleblower protections extend to reports of actions that threaten public health, safety, or the environment.

Whistleblowers are generally protected against employment termination and other retaliation or harassment by employers and other employees. Federal whistleblower protections are largely limited to reports of misconduct associated with workplace health and safety and environmental protection, but under some circumstances whistleblowers who report government contracting fraud or misconduct or securities law violations may also qualify for federal whistleblower protection. Some states provide broader whistleblower protection.

Whistleblower protection requires proof that the report of misconduct is based on a reasonable assessment of the circumstances. Written references to engineering codes of ethics can be helpful on this point. If an engineer has clearly expressed his or her concerns within the relevant organization and cited appropriate codes of ethics, and if despite those concerns the organization continues the conduct, the engineer can present this history to the appropriate legal or regulatory authority.

Documentation of a dispute and associated professional concern can help to persuade an authority of the reasonableness of the engineer’s claim, thus facilitating a request for whistleblower status.

1 A list of selected professional societies with posted codes of ethics follows this article.

2 Another 18 states provide whistleblower protection only for state government employees.
Protection from Retaliation

Codes of ethics can help engineers pursue their own legal action against an employer or client if the engineer faces reprisals as a result of expressions of concern or refusal to follow orders. In many states, courts recognize claims of wrongful termination raised by employees against employers, but employees bear the burden of demonstrating that the termination of employment was illegal.

Documentation that the engineer raised reasonable concerns of illegal, fraudulent, or potentially harmful conduct by the employer strengthens the engineer’s case. By demonstrating that the engineer’s actions were motivated by reasonable professional concerns—an argument made more compelling through reference to specific codes of ethics—the engineer presents a stronger case that the termination was retaliatory and not justified by insubordination.

If government authorities, including law enforcement and regulatory agencies, or individual people harmed by a product or service raise legal claims against an individual engineer, the documentation of that engineer’s concerns and objections based on the terms of codes of ethics can enhance the engineer’s defense against personal liability. That documentation can help to transfer liability from the engineer to the employer or client.

Conclusion

Codes of ethics provide important tools to help engineers protect themselves against reprisals and personal legal liability. They also facilitate efforts by engineers to exercise their personal rights in interactions with their employers and clients. Professional engineers should recognize this significant value of the codes and should, in consultation with their personal lawyers, be sure to integrate the code provisions in their daily professional actions.

Professional Society Codes of Ethics (selected list)

American Institute of Chemical Engineers: www.aiche.org/about/code-ethics
American Society of Civil Engineers: www.asce.org/code-of-ethics
Association for Computing Machinery, Software Engineering: www.acm.org/about/se-code
Institute of Electrical and Electronics Engineers: www.ieee.org/about/ieee_code_of_conduct.pdf
National Society of Professional Engineers: www.nspe.org/resources/ethics/code-ethics

An extensive list of national and international organizations and their codes of ethics is available from the Illinois Institute of Technology (http://ethics.iit.edu/ecodes/ethics-area/10?title_op=word&title=).

References

Engineers can better serve the public by considering costs and benefits in addition to failure, and by working more closely with the public.

Beyond Protecting the Public from Risk

Robert B. Gilbert

A common perception is that engineers’ responsibility is to protect the public from risk. This perception is reinforced in engineering design guidelines and standards that focus on minimizing the chance of failure for engineering systems. However, the reality of what the public is willing to accept indicates that it is not necessarily averse to risk.

What if the public is not averse to risk? It would mean that upholding the first canon in the engineering code of ethics, “Engineers shall hold paramount the safety, health, and welfare of public,” is not necessarily best achieved by minimizing the chance of failure. Maybe the optimal solution is to expend more resources to enhance welfare by taking on additional risk. The key is that the engineering profession does not and cannot know the best interest of the public’s welfare without substantively and continuously interacting with the public it serves.

This article first presents evidence that the public is not necessarily averse to risk. It then suggests practical means for the engineering profession to hold paramount the safety, health, and welfare of the public beyond minimizing the chance of failure for engineering systems. Last is a discussion of the important role of engineering education in helping engineers work with the public to manage risk. Managing risks from floods is used throughout to illustrate the points.
Is the Public Averse to Risk?

On the 10-year anniversary of Hurricane Katrina, the New Orleans District Commander for the US Army Corps of Engineers, Col. Richard Hansen, said the following (US Army 2015; emphasis added): “The nation made a commitment after Katrina to protect the city and areas affected by the hurricane” and the engineers “made a promise to themselves and to the agency that [Katrina] wasn’t going to happen again.” The result is the Hurricane and Storm Damage Risk Reduction System. At about the same time, a few years after Superstorm Sandy, New York City announced that it “will spend $100 million to build a new flood protection system to shield lower Manhattan from major storms” (Durkin 2015; emphasis added).

This intent to protect the public from risk is manifested in engineering policy and design guidelines. The US government has established guidance for the level of risk associated with flooding from major dams that is considered “unacceptable” (figure 1). In the spirit of the intent to reduce risk, these thresholds are comparable to the risks to the public from meteorites (USNRC 1975; Whipple 1984).

It is possible, however, that a public aversion to risk is more perception than reality. Recent assessments of flooding risks for a variety of levee systems in the United States indicate that the risk levels actually achieved are between ten and more than a thousand times greater than the guidelines for flooding from major dams (figure 1).

Furthermore, the public is not willing to spend an unlimited amount to reduce risks. In New Orleans, the $17 billion spent to upgrade the system of flood levees, walls, and gates after Hurricane Katrina corresponds to about $100,000 invested per expected life saved over its 100-year design life. For context, US guidelines for environmental regulations consider a threshold cost of about $10,000,000 per expected life saved (Borenstein 2008).

1 For example, there was some public discussion about spending more money on the levee system in New Orleans, using a 500-year versus 100-year design basis, but after resistance to the idea it was not pursued.
There is no absolute threshold for what the public wants or will accept or reject concerning risk because there are benefits and costs at play. There are benefits to living in New Orleans, the fourth largest port in the world; the California Delta, the state’s primary supply of water; and Washington’s Green River Valley, a major hub of commerce and trade. Thus people do not always appear to be logical in making decisions in the face of uncertainty, and they do not consistently choose to minimize or even reduce risk (e.g., Smutniak 2004).

For these reasons, upholding the first canon in the engineering code of ethics, to “hold paramount the safety, health, and welfare of the public,” does not necessarily mean “reduce all risk.” It means working with the public to develop an optimal balance of benefits, costs, and risks on a case-by-case basis in making decisions and developing effective engineering solutions.

**People are not always logical in the face of uncertainty, and do not always choose to minimize or even reduce risk.**

**Beyond Minimizing the Chance of Failure**

Engineering design practice tends to focus on reducing or preventing the possibility of failure: preventing loads from exceeding capacities, preventing deformations from exceeding allowable values, preventing motions from exceeding tolerable thresholds. The title and lede of a recent cover story in *PE Magazine* illustrate this emphasis: “Tragic Reminders. Recent events such as tainted drinking water, a safety scare in the nation’s capital, and a toxic waste release reiterate the irreplaceable role that professional engineers play in ensuring the public health, safety, and welfare” (Kaplan-Leiserson 2016).

There are many important considerations in design beyond reducing the chance of failure:

- How does the system perform after it has “failed” and can it be designed to fail gracefully? Can a floodwall be designed to gradually pass water as the flood pressure increases (e.g., with cleverly designed fuses), rather than abruptly collapsing and releasing a powerful rush of water that can cause significant damage to property and life?
- What are the possible consequences of a failure and available means to manage them? In addition to checking the hydraulic, geotechnical, and structural stability of a levee system, how about including checks of the transportation system for the capacity, efficiency, and quality of evacuation?
- Can the system be readily adapted to changing conditions in the future? If the 100-year flood level changes with new information or due to changing climate or land-use conditions, can the heights of levees or walls be raised (or lowered) efficiently in the future?
- What is the actual lifetime of an engineering system and how can it be controlled? If the design life for a levee system is 50 years, can it be designed to be readily reused, relocated, or modified at the end of 50 years?
- What are the risks, costs, and benefits associated with providing for different chances of failure? Instead of focusing only on the most cost-effective way to meet a design criterion, what is the optimal balance of risks, costs, and benefits for a specific project?

Design standards and guidelines (i.e., precedent) play a significant role in advancing engineering beyond reducing the chance of failure. Progressive design approaches that promote rather than stifle creative and “nonstandard” solutions are needed. If the optimal solution depends on project-specific risks, costs, and benefits (and may change with time), then there cannot be uniform or absolute design criteria. If an impediment to successful evacuation in advance of a flood is the infrequency of the need (i.e., people are surprised and not prepared), then is a better solution to design for more frequent flooding so that preparedness is a regular way of life?

Moreover, design practice tends to focus on components (e.g., individual columns, piles, levee reaches, gates, or pumps), whereas it is the performance of the system that really matters to the safety, health, and welfare of the public. Design approaches must consider the performance of the overall system, including how it might fail and how the consequences of a failure can best be managed.

---

2 Note that the first canon in the code of ethics is to “hold paramount,” not “ensure,” the safety, health, and welfare of the public.

3 The quality of an evacuation is determined by factors such as people’s ability to take their pets and the availability of suitable shelters to accommodate evacuees.
In addition to improving design standards and guidelines to better address factors beyond failure, the engineering profession needs to engage and listen to the public in order to serve the public welfare:

1. Involve the public meaningfully in significant design decisions. The stakeholders paying for and affected by a levee system should participate in establishing the level of protection provided by that system.

2. Communicate clearly with the public about the costs, benefits, and risks of different design alternatives. If members of the public are going to be engaged, they need to be as informed as possible in participating in the decision making.

3. Engage the public from the beginning and throughout, from conception to design, implementation, and operation. A single public meeting in which the preferred solution is presented for comment is not an effective way to involve the public.

4. Recognize that the public is diverse, with as many perspectives and values as there are individuals. While consensus may be impossible, transparency, effective communication, and active inclusion are all achievable.

5. Work collaboratively and continuously with non-engineers who are experts in public relations, sociology, psychology, public health, and economics. Effectively engaging the public requires expertise far outside of engineering, and it is the ethical responsibility of engineers to not practice in areas outside of their competence.

6. Ensure that the expertise of the engineering profession is included in major policy and design decisions.

7. Be open to criticism and change. While there are “rights” and “wrongs” in mathematics, there are no single “right” solutions to serving the welfare of the public. Solutions may change over time and with setting.

In the example of managing risks from floods, the optimal solution for public welfare may be to spend more resources on levees at the expense of resources allocated to major dams, or to spend more on land-use planning and evacuation and less on levees and dams.

Role of Engineering Education

Engineering education plays a key role in moving beyond protecting to serving the public. The challenge is that traditional engineering education is centered on mathematics—math classes dominate the technical classes in the first two years of a typical undergraduate curriculum and are prerequisites to nearly every other technical class.

Math is clearly necessary, but there are two downsides to this strong focus.

1. There are right and wrong answers in math. Even in probability and statistics, the subject is traditionally taught with problems where there are single correct answers for a probability value or a confidence interval.

2. Math is an individual exercise that does not require communication, interaction, or collaboration.

Thus although math is essential to solving engineering problems effectively, additional knowledge, skills, and perspectives are essential to best serve the public.

A single public meeting in which the preferred solution is presented for comment is not an effective way to involve the public.

Uncertainty

Engineering education should embrace uncertainty throughout the curriculum. There needs to be a consistent message to all students, from freshman to continuing education classes, that there is uncertainty, that it is not bad, and that there are effective techniques to help manage it.

- Illustrative examples of uncertainty should be presented in every subject. For example, the 100-year wave height in the central Gulf of Mexico was 22.6 m based on nearly a century of data—until three hurricanes in just two years (2004 and 2005); it is now 28.1 m (API 2013).

- Practical exercises should be developed and implemented to help students learn how to assess uncertainty. Meteorologists are very effective at assessing (and communicating) uncertainty because they have to practice it every day.

- Problems and case histories should be provided in which uncertainty is managed by developing solutions that are either insensitive to the uncertainty
or that accommodate the range of possibilities posed by the uncertainty. One example of a case history is engineers’ finding that offshore oil and gas platforms with four or more legs fared much better than those with three legs when wave heights exceeded design values, thanks to the added redundancy and robustness (Energo Engineering 2007, 2010).

**Experiential Learning**

Engineering education should rely more heavily on experiential learning. The best way for engineers to learn how to interact with and serve the public is to practice doing it. Structured exercises, preferably working on real problems with real public stakeholders, should be integrated into all levels of engineering education. The key to an exercise being structured is to allow for the possibility of failure, because the best learning comes from failure:

- When students are unprepared at a meeting with city representatives they learn that they better have a firm grasp of codes and regulations before they start trying to solve a problem.

- When students are questioned by a professional engineering mentor about an unreasonable cost estimate they learn to be careful about reviewing and understanding the information they present.

- When students inadvertently promise the public something that is not possible they learn about ethical responsibility.

An added benefit of practicing on real-world problems is that the students are both serving the public before graduating and, in the process, educating the public about engineering.

**Public Involvement**

Engineering education should emphasize public involvement. Engineers should be an integral and active part of all communities, from neighborhood associations to Congress. Encouraging engineering students to participate in local planning activities could lead to greater participation throughout their careers and possibly even lead to more engineers running for public office.

**Summary**

Holding “paramount the safety, health, and welfare of public” is not necessarily best achieved by minimizing the chance of failure. Instead it is achieved by working with the public to develop an optimal balance of benefits, costs, and risks on a case-by-case basis in making decisions and developing effective engineering solutions. The catch is that it is easier to minimize failure than it is to figure out what best serves the interests of the public.

Engineers can better serve the public by addressing not only the chance of failure in design but also factors such as performance, adaptability, endurance, and costs and benefits. They should also develop more progressive design standards and guidelines, and work more closely with the public. These opportunities can be realized by improving engineering education so that students embrace uncertainty, practice on real projects, and understand the importance of public involvement.

**References**


Flawed or misused analytic techniques for assessing pollution risk can allow environmental injustice, disproportionate health harm to children and to poor or minority communities.

How Some Scientists and Engineers Contribute to Environmental Injustice

Kristin Shrader-Frechette

As Danny Glover put it, environmental injustice (EIJ) is about the fact that South-Central Los Angeles children have only one-third of the lung capacity of Santa Monica children (van Gelder 2001). South-Central LA is mostly black and heavily polluted; Santa Monica is mostly white and pristine. Children bear the brunt of the difference.

In most nations poor people, minorities, and children bear EIJ—disproportionate pollution that causes poorer health and higher death rates. This article shows how scientists and engineers contribute to EIJ if they mask, thus encourage, EIJ by using flawed analytic techniques such as short-term studies or incomplete verification and validation. It illustrates EIJ effects of three such errors: using small or nonrepresentative samples, misrepresenting uncertainty, and misusing statistical significance.

Background

Each year US industry releases into the environment more than 4 billion pounds of toxic chemicals that contribute to the 40 percent of all global disease and premature death caused by environmental factors, especially pollutants (CEHC 2016; Pimentel et al. 2007). The World Health Organization (WHO 2014) says air pollution alone causes 7 million global, annual, premature, preventable deaths.
But pollution doesn’t affect everyone equally. People of color are a majority of residents living within 3 km of US hazardous-waste sites, and they are 3–9 times more likely than whites to be exposed to toxin-releasing facilities such as waste incinerators (Bullard et al. 2008; Lougheed 2014). Of nearly 4 million residents living within the fenceline zones\(^1\) of 3,433 US chemical facilities, the proportion of blacks is nearly 100 percent greater than their percentage of the US population, and the percentage of Latinos is 60 percent greater (Orum et al. 2014).

Poor and minority children are hurt worst by EIJ, partly because infants and children have unique biological vulnerabilities, proportionately heavier pollution exposures, and higher respiration rates and sensitivities. Rates of ADHD, asthma, autism, birth defects, cancer, and reduced IQ have all been rising, at least partly from increased environmental pollution, including exposure to 80,000 synthetic chemicals, most of which did not exist 50 years ago (Grandjean 2013; Grandjean and Landrigan 2014). Of the 20 US highest-volume toxic-chemical releases, physicians say 75 percent are known or suspected to be neurodevelopmentally toxic to children (CEHC 2016).

**Why EIJ Continues**

For two-thirds of the 3,000 high-production-volume chemicals (those with a production volume of at least 1 million pounds/year), the US government has no information on their child-harm potential. One reason is the failure of the 1976 Toxic Substances Control Act (TSCA), including its grandfathering 62,000 already-in-use chemicals without any testing.

**The Industry-Government Funding Imbalance**

Another reason for EIJ and poor pollutant information is chronic underfunding and understaffing of the US Environmental Protection Agency (EPA), responsible for enforcing TSCA. The result? Without overwhelming evidence to the contrary, regulators typically presume existing pollutants are safe (GAO 2015, pp. 280–287; Grandjean and Landrigan 2014).

A further reason for EIJ and poor pollutant information is the industry-versus-government science-funding imbalance. Industry’s annual spending on environmental-health research is 100 times that of government, and its scientific results often are protected by trade-secrets laws (Shrader-Frechette 2007a, pp. 76–112). Coupled with financial conflicts of interest, this funding imbalance means that industry-funded research may use flawed science to generate pro-industry conclusions (Krimsky 2004). For instance, one false-negative bias—that masks EIJ—involves giving averages or point estimates instead of ranges or distributions of pollution levels. Yet pollution at the tail of the distribution, not average levels, typically hurts people.

**Flawed Science about Product and Pollutant Harm**

Still another reason for EIJ is weak regulations. Epidemiologist David Michaels (2008), President Obama’s assistant secretary of labor, says the US health-regulatory system is broken because flawed science and engineering dominate it and encourage EIJ. He shows how unscrupulous product-defense, contract-research, and private consultants misuse analytic techniques, “manufacture” uncertainty about obvious product/pollutant harm, control the scientific literature, and thus derail needed regulations.

**The 1976 Toxic Substances Control Act grandfathered 62,000 already-in-use chemicals without any testing.**

Of course, most researchers never fall into research misconduct—that is, falsification, fabrication, or plagiarism (ORI 2011). Statistically, however, because biased methods can give funders the results they want, social scientists agree that knowing the funder generally predicts science and engineering results (Krimsky 2004).

Investigating flawed scientific techniques in the chemical industry, a prominent US National Research Council report warned that “a study cannot be ethically acceptable if it is scientifically invalid,” for example, if it lacks “adequate statistical power” or is not “reported comprehensively” (NRC 2004, p. 7).

Besides being unethical, invalid science and engineering also can cause EIJ. Three of many flawed analytic

---

\(^1\) The fenceline zone is an “area designated as one-tenth the distance of the vulnerability zone, in which those affected are least likely to be able to escape from a toxic or flammable chemical emergency” (Orum et al. 2014, p. 1).
techniques that encourage EIJ include employing small or nonrepresentative samples, misrepresenting uncertainty, and misusing statistical significance.

**Employing Small or Nonrepresentative Samples**

When scientists or engineers test samples that are nonrepresentative or include only a few of many instances or subjects, they risk false negatives, false conclusions of no harm. A typical case in which scientists appear to have drawn false conclusions of no harm, at least partly because of their small, nonrepresentative samples, is the 2015 joint EPA and auto-industry Advanced Collaborative Emissions Study (ACES).

---

**Early environmental pollution exposures often “program” children for different diseases later in life.**

---

**The Controversial “Clean-Diesel” Research**

ACES assessed the health effects of “clean diesel” (as defined by 2007 US air-pollution standards). After using several questionable methods, such as employing no positive controls, inaccurate state variables, and small, nonrepresentative samples (Shrader-Frechette 2015), ACES concluded that “clean diesel” is neither carcinogenic nor genotoxic (Greenbaum et al. 2015).

Despite its denial of carcinogenicity and genotoxicity, ACES admits that “clean diesel” (which removes only some diesel-particulate matter [DPM] from regular diesel exhaust) still contains 200,000–800,000 DPM particles per cubic centimeter (Greenbaum et al. 2015; McDonald et al. 2015). Yet DPM has no safe dose. Each particle can move directly and immediately into the brain and lungs, then to the blood and all organs, where it causes inflammation, oxidative stress, blockage, disease, or death (APHA 2014; CalEPA 2007; IARC 2012; Pope and Dockery 2006; Pope et al. 2009; Shrader-Frechette 2015; US EPA 2013).

No wonder the WHO, International Agency for Research on Cancer, American Public Health Association, and most scientific and medical groups say that any amount of diesel exhaust is carcinogenic. They say “strong evidence” shows that diesel, especially DPM, induces cancer in humans through genotoxic mechanisms. Decades-long, controlled, 600,000-person studies, across the US, have shown that any nonzero DPM or PM exposure increases risks such as Alzheimer’s, autism, birth defects, cancer, cardiovascular disease, Parkinson’s, and respiratory disease (e.g., Costa et al. 2014; Krivoshoto et al. 2008; Oudin et al. 2016; Pope and Dockery 2006; Pope et al. 2009; Raz et al. 2015; Shrader-Frechette 2015; Terzano et al. 2010).

**ACES Tested Only the Healthiest, Least-Sensitive Individuals**

One reason ACES rejected scientific consensus about diesel risks appears to be that it used only short-term studies. ACES claimed to have done “lifetime” exposure studies of “clean diesel,” but instead tested only rats at the middle, healthiest parts of life. This is equivalent to testing only humans older than age 6—far beyond the period when children can be up to 40 times more sensitive than adults. This sensitivity explains why many prominent scientists have documented higher rates of child autism and IQ losses that are proportional to higher PM and DPM traffic exposures (e.g., Becerra et al. 2013; Harris et al. 2015; Makhijani et al. 2008; Raz et al. 2015).

Using such nonrepresentative samples (McDonald et al. 2015), ACES ignores the way that early environmental pollution exposures typically “program” children for various diseases later in life (e.g., Grandjean 2013; Grandjean and Landrigan 2014). By preselecting subjects that had no typical infant or juvenile exposure, ACES was less likely to detect diesel harm.

**ACES Tested Only Small Samples, 3–5 Rats**

In addition, ACES’ samples of only 3–5 rats, at each of 4 exposure levels (McDonald et al. 2015), are too small by a factor of 1000 to detect most harm (Shrader-Frechette 2015). ACES’ small samples are puzzling because using thousands-of-rats samples would have been easy and inexpensive, compared to human testing (e.g., Hamra et al. 2015).

This small-sample bias thus masks diesel’s EIJ harm, not only to sensitive populations such as children and sick or elderly people, but also to minority and poor people who tend to live near highways where DPM is highest. In Los Angeles County, for instance, mobile pollution sources like vehicles generally cause 90 percent of the total cancer risk from air pollution, but DPM alone causes 80 percent of this risk (South Coast AQMD 2015).
How Small, Nonrepresentative Samples Mask Harm and Help Cause EIJ

Because nearly all US freight trucks and trains use diesel fuel, intermodal-freight-transport hubs and highways have especially high DPM levels. Yet because hub neighborhoods are mostly African-American or Latino, they bear diesel EIJ (Hricko et al. 2014; US EPA 2014). The mostly Latino residents of the Los Angeles neighborhood surrounding the East Yards intermodal-freight-transport facility, for instance, have cancer rates up to 19 times higher than average-US rates, and 11 times higher than Los Angeles County rates (CalEPA 2007; US EPA 2013).

Chemical-Industry Small Samples

Why has government not prevented the higher cancer rates in areas like East LA? One reason is that small-sample, nonrepresentative pollution testing, like what ACES did, allows many polluters to tell both government and EIJ victims that their air, water, or food is safe when it is not. Polluters have used small samples for a long time, and they usually get away with doing so.

For instance, in 1993 the US National Research Council (NRC 1993) warned about likely child-neurodevelopmental harm from then-current pesticide regulations. As a result, Congress directed EPA to reassess possible harm and imposed stricter pesticide regulations during the 10 years of reassessment.

Yet EPA found no neurodevelopmental harm, and it rejected the stricter pesticide regulations. Why? Part of the reason is that it relied on pesticide studies presented by the chemical industry. All 22 chemical-industry studies—submitted to EPA in response to the stricter pesticide regulations—had small samples, averaging only 25 subjects. Yet only sample sizes hundreds of times larger could avoid most false-negative conclusions that current pesticide regulations were safe. In addition, all chemical-industry studies had further false-negative biases because they were only hours or days long, far too short a time to detect neurodevelopmental harm (Shrader-Frechette 2007b).

Misrepresenting Uncertainty

Researchers also can bias their results and contribute to EIJ when they misrepresent uncertainty or fail to do uncertainty analysis, a statistical assessment of the reliability of scientific or engineering judgments about the values attributable to estimates, models, or measures. Whenever such values are untestable, rely on unknowns, or reflect cumulative effects of data variability, uncertainty analysis can assess both random error and bias (Jordaan 2005; Shrader-Frechette 2007a, pp. 76–112).

Uncertainty analysis is especially needed when scientists or engineers estimate long-term, inaccessible, or difficult-to-predict harm, such as 10,000-year effects of climate change—or the timing, route, and volume of pollutants that may escape from a hazardous-waste site. Otherwise, experts’ well-documented overconfidence, representativeness, anchoring, and other cognitive biases could compromise sound science and promote EIJ (Bullard et al. 2008; Kahneman et al. 1982).

Small-sample pollution testing can allow polluters to tell government and EIJ victims that their air, water, or food is safe when it is not.

The Flawed MIT Study

Yet even well-known engineering analyses, like the classic MIT study of commercial-nuclear-accident probabilities, misrepresent uncertainty either through subjective assumptions or failure to do uncertainty analysis. The MIT engineers relied on purely theoretical calculations, assumed that control-rod and other failure probabilities were independent, then concluded that nuclear-accident risks were only 1/17,000 per reactor-year, about 1 in 5 for all US reactors during their lifetimes. Unsurprisingly, the American Physical Society and US Nuclear Regulatory Commission said they do “not regard as reliable” the MIT “numerical estimate of the overall risk of reactor accidents” (Shrader-Frechette 2014; US NRC 1975, 1979).

Even worse, US, Dutch, and other engineers showed that the MIT study ignores empirical data, exhibits overconfidence biases, thus overestimates nuclear safety. When they compared actual US reactor-accident frequencies from Oak Ridge data, with the MIT predictions for the same 7 events, the actual occurrence rates for all 7 accident types were outside MIT’s 90-percent-confidence bands. The MIT authors said these accidents had only a 10 percent probability. Simply checking available empirical data could have avoided
misrepresentation of uncertainty (e.g., Cooke 1982; Shrader-Frechette 1991, 2007a; US NRC 1975).

Biased DOE Studies

Similar misrepresentations occurred when US Department of Energy (DOE 2000) engineers assessed the million-year safety of the proposed Yucca Mountain, Nevada, nuclear-waste repository. After DOE failed to do uncertainty analysis, then made optimistic predictions about repository safety, scientists from the International Atomic Energy Agency used DOE’s own data to do uncertainty analysis. The results were damning. DOE’s overconfident estimates of low radiation doses were uncertain by 9–12 orders of magnitude. Yet if they erred by only 2 orders of magnitude, catastrophic numbers of deaths could occur (IAEA 2001; Shrader-Frechette 1993, 2007a).

Both the MIT and DOE misrepresentations of uncertainty arguably have contributed to false-negative biases, thus EIJ risks, as US commercial reactors are disproportionately sited in predominantly poor, southeastern US communities. Yucca Mountain was sited near predominantly Native American and Latino communities (Shrader-Frechette 2011).

Misrepresentation of uncertainty has been a key cause of disproportionate siting of US commercial reactors in poor communities in the Southeast.

Misusing Statistical Significance

Researchers also contribute to false-negative conclusions and EIJ byinvalidly rejecting observational/epidemiological evidence of pollution harm if it is not statistically significant. However, statistical-significance tests are valid only with randomized, representative samples, randomized assignment to experimental-versus-control groups, and randomized dosing and treatment. Without randomization (that typically ensures parent- and sample-population homogeneity), reliable inferences are impossible (Greenland 1990; Shrader-Frechette 2014).

Yet scientists and engineers frequently demand statistically significant results from nonrandomized data, or they invalidly deny health damage from pollutants, e.g., near toxic-waste dumps. With hundreds of thousands of such US dumps, disproportionately sited in poor or minority communities, invalid statistical analyses can promote EIJ (Bullard et al. 2008; Rushton 2003; Shrader-Frechette 2012, 2015; Triassi et al. 2015.).

Flawed Statistics about Three Mile Island

Consider what happened at Three Mile Island (TMI), Pennsylvania. The US government and nuclear industry claim that “no member of the public died” because of the 1979 nuclear accident (e.g., WNA 2016), partly because they reject key epidemiological evidence of harm, as not statistically significant (Hatch et al. 1991, 1990; Shrader-Frechette 2014; Talbott et al. 2003).

Yet by definition, after-the-fact accident data cannot be randomized, thus validly assessed for statistical significance. No wonder most university epidemiologists who study TMI disagree with the industry-government, no-deaths claim. Only four years after the accident, already there was a 64 percent increase in cancer incidence within 10 miles of TMI. This represents about 126,000 cancers that otherwise would not have occurred (Hatch et al. 1990; Shrader-Frechette 2014; Wing 2003).

These observational, nonrandomized data are especially damning to the no-deaths claim because the increased cancers were disproportionately radiosensitive, exactly what a nuclear accident would cause. They also were disproportionately respiratory, predictable because TMI released mostly radioactive noble gases (Shrader-Frechette 2014; Wing 2003).

UN documents report that TMI radiation doses were 100,000 times higher per hour than industry and government claim. They say TMI released 10 times more radiation than Hiroshima-Nagasaki, while the Chernobyl accident released 200 times more radiation than Hiroshima-Nagasaki (Shrader-Frechette 2011, 2014; WHO 1995).

But if scientists and engineers do not dismiss Hiroshima-Nagasaki harm, why should they dismiss TMI harm? Even after the highest TMI releases ended, the US NRC admitted that additive, hourly TMI-offsite doses were higher than yearly average-background-radiation doses that annually cause 3–6 percent of all cancers.
Under oath, the TMI utility also admitted in court that hourly TMI doses were more than double the yearly background doses and 6 times greater than the many-months TMI-maximum dose that the US NRC claimed (Shrader-Frechette 2014; Walker 2006).

Who was hurt most because of the industry-government demand for statistically significant results and the resulting denial of TMI harm? Children. They're up to 40 times more sensitive than adults to the same radiation doses (Makhijani et al. 2006).

TMI insurers quietly spent $80 million to require gag orders in exchange for paying off the worst TMI-accident victims of cancer, infant retardation, and infant mortality, all of which can be caused by high radiation doses. The insurers then rejected thousands of other claims, mostly on behalf of children, partly by claiming that the increased numbers of cancers, to date, were not statistically significant (Epstein 2011; Shrader-Frechette 2014; Wing 2003).

**Denying EIJ**

In response to apparent EIJ, critics typically either deny or excuse the harm. Those who deny EIJ say health risks near hazardous facilities need not be higher than elsewhere, just because pollution releases are higher (Boerner and Lambert 1997; Hayward 2009).

These EIJ deniers are partly right; emissions do not equal exposures. However, studies on thousands of airborne pollutants show clear dose-response curves that correctly predict dose-related harm. Unequivocal data show that the closer one gets to noxious facilities, the higher the health risks and the lower the resulting property values (Anstine 2003; APHA 2007; Muehlenbachs et al. 2015).

Deniers also say that EIJ disappears when supposedly victimized areas are redefined. EIJ can vanish when victims are defined as living within 50, rather than 5, miles from a hazardous site (Boerner and Lambert 1997).

Deniers are right that dilution sometimes can be a partial solution to pollution, getting farther away from hazards. Yet those who deny EIJ don’t dilute near-facility pollution, only their methods of detecting pollution. By including less- and non-exposed people over a larger area, they reduce average-pollution doses. Thus the appropriate response to apparent EIJ is not gerrymandering that masks spatially related effects, but scientific analysis that can discover any disproportionate pollution burdens anywhere (Gracia and Koh 2011).

EIJ deniers likewise claim that the correlation between hazardous sites and poor/minority residents does not prove that polluters caused EIJ. They say poor people/minorities may have moved to risky areas after facility siting (Hayward 2009; Mohai and Saha 2015).

Yet here again, EIJ deniers partly err. The issue is not only whether siting decisions deliberately victimize or target poor people and minorities, given that lower-socioeconomic-status neighborhoods are less able to force costly pollution controls. Instead, the issue is also that even when there is no deliberate discrimination, government should guarantee everyone rights to life, to equal opportunity, to breathe clean air, to drink clean water, and to be protected from environmental toxins (Shrader-Frechette 2004).

---

**The main EIJ victims of TMI, hurt by invalid demands for “statistically significant” results, were children.**

---

**Excusing EIJ**

Still, those who excuse EIJ often claim that because polluting facilities must be located somewhere, different pollution levels are unavoidable. Or they say that because of factors like cheaper housing, EIJ victims benefit overall by living near noxious facilities.

The unavoidability excuse for EIJ begs at least two questions. Should pollution burdens be distributed unequally, all other things being equal? Should people’s rights to breathe clean air depend on their race or socioeconomic status?

This excuse also ignores the fact that a more equal distribution of pollution burdens likely would force the US to bring all pollution standards at least up to those of Europe, which often has better protections. For instance, US per-capita CO\(_2\) emissions are about 20 tons/year, but 10 in the UK, 8 in Italy, 7 in France, and 6 in Denmark—countries where there is much more public transport, recycling, green energy, and pollution-control expenditures per dollar of GDP. The United States has up to 300 percent more CO\(_2\) emissions per dollar of GDP than EU nations like Germany,
Italy, Sweden, and the UK (Rosenthal 2009; Shrader-Frechette 2007a; World Bank 2011). \(^2\)

Likewise the overall-benefits excuse for EIJ begs the question that cheaper housing near polluting sites is worth killing or sickening innocent people. It also ignores the fact that people have legal and moral rights to equal treatment—long-standing common-law rights not to be harmed by others. If US equality means anything, Americans should bear mostly equal pollution burdens (Shrader-Frechette 2004).

But do overall economic benefits excuse EIJ?

Those who think so always ignore the massive economic costs of pollution-induced poor health. Just the current IQ losses and their resulting lifetime-earnings losses, just from lead pollutants (mostly from incinerators and factories, not lead paint), just for the one-year cohort of US children under age 5, are $51 billion/year. Child-IQ and resulting economic losses attributable to lead, pesticides, and other neurotoxic pollutants are each roughly the same as those for preterm birth, traumatic brain injury, brain tumors, and congenital heart disease. Why does the US try to prevent the four preceding medical problems, while it allows EIJ (Attina and Trasande 2013; Grandjean and Landrigan 2014)?

**Conclusions**

Scientists and engineers ought not use or misuse analytic techniques that mask, thus encourage, EIJ. Sound science promotes sound ethics, including environmental justice.

**References**


\(^2\) Country-specific data are available online from the World Bank, CO2 emissions (metric tons per capita), at http://data.worldbank.org/indicator/EN.ATM.CO2E.PC.


Modelers must consider decisions from multiple perspectives, to take account of both their own values and those of their users.

Ethical Implications of Computational Modeling

Kenneth R. Fleischmann and William A. Wallace

At their core, science, engineering, and all forms of inquiry involve making sense of a complex world. Modeling is one way of reducing the complexity of the world by abstracting away details.

Computational modeling involves the use of computers to scale up mathematical models.\(^1\) Computational models play a critical role in a number of application areas. For example, agricultural engineers use them to control invasive species (Büyuktahtakin et al. 2014), and climatologists use them to predict changes in the Earth’s climate over time (Edwards 2010). In tennis the “Hawk-Eye” instant replay system is used to resolve challenges to refereeing: unlike instant replay used in most sports, it employs a computational model to track the ball using multiple camera angles and makes a prediction about whether a ball was in or out (Collins and Evans 2008).

Kenneth R. Fleischmann is an associate professor in the School of Information at the University of Texas at Austin. William A. Wallace is Yamada Corporation Professor in the Department of Industrial and Systems Engineering at Rensselaer Polytechnic Institute.

\(^1\) Nature.com defines computational models as “mathematical models that are simulated using computation to study complex systems. In biology, one example is the use of a computational model to study an outbreak of an infectious disease such as influenza. The parameters of the mathematical model are adjusted using computer simulation to study different possible outcomes.” Available at www.nature.com/subjects/computational–models.
In each of these cases, computational modeling carries important ethical implications, as modelers have tremendous power to influence both perceptions and behavior, particularly when models are not transparent (Fleischmann and Wallace 2005).

**Background: Stakeholders and Power Inequities**

To understand the ethical implications of computational modeling, it is first important to understand the key stakeholders involved in the computational modeling process. Modelers build models to specifications dictated by clients, for use by end users, and use of the model also affects others indirectly.

There are often power inequities, as clients and modelers may not be sensitive to the needs and values of end users and those affected. End users may not be able to influence or even understand how models work, and those affected may not even realize that a computational model is being used.

---

**People may place blind trust in a technology without a full understanding or even awareness of the technology or how it works.**

---

For example, in the case of Hawk-Eye, the computational model was built for the use of International Tennis Federation officials, whose decisions affect both the players and the tennis public. The public and often the players themselves are unaware that a computational model is being used, and ultimate authority is ceded to the reconstruction produced by that model, with no attention given to the degree of error in the model’s calculations—rather, the call is treated as infallible, unlike the human chair and line umpires (Collins and Evans 2008).

People thus place blind trust in a technology without a full understanding—or even awareness—of the technology or how it works (or, in some cases, does not work). This creates the possibility of being subjected to technocracy, where people are forced to blindly trust technology and those who create it, a significant threat to democracy and individual autonomy.

---

**Role of Human Values in Computational Modeling**

This paper synthesizes research findings from a three-year field study of the role of human values in computational modeling (Fleischmann and Wallace 2006, 2009, 2010; Fleischmann et al. 2010, 2011a,b, 2017). The study involved field research at three computational modeling laboratories—corporate, academic, and governmental—in 2006–2008. We visited each site three times: a short visit to conduct information sessions, a longer visit to conduct interviews, and a short visit to present our results and conduct confirmatory focus groups. Data collection was based on 76 surveys completed and interviews with 40 of the respondents. We analyzed the interview data using thematic analysis (Braun and Clarke 2006) based in part on the Schwartz (1994) Value Inventory of 56 basic human values. We received IRB approval before starting the research, and all participants were given the option to review and modify their interview transcripts.

To synthesize the study findings, we discuss the roles of value conflicts (Fleischmann and Wallace 2006, 2010; Fleischmann et al. 2011a), transparency (Fleischmann and Wallace 2005, 2009; Fleischmann et al. 2011c), and professional and organizational cultures, particularly professional codes of ethics (Fleischmann et al. 2010, 2011b, 2017). We then apply these findings to shed new light on the broader ethical challenges raised by computational models (Wallace and Fleischmann 2015).

**Value Conflicts**

What is the relationship between values and computational models? Pielke (2003) distinguishes between the modeling process and models as products. Building on the work of Winner (1986), Johnson (1997) argues that values can be embedded in technology. We found values that were embedded in the models themselves and values that arose during the modeling process, as well as examples of values’ influence on the success of both the modeling process and models as products (Fleischmann and Wallace 2006).

Values are not typically exclusive—that is, held by some but not by others. In travel safety, for example, there is a value conflict between security and convenience. It’s not that some people value security while others do not, and that some people value convenience while others do not. Rather, the issue is in how people make tradeoffs between these values, and the extent to which people value one versus the other. We found that value conflicts played an important role both in the
modeling process and in models as products (Fleischmann and Wallace 2010).

Conflicts in the Modeling Process

We found that the modeling process hinged largely on value conflicts such as honesty versus obedience, innovation versus reliability, and timeliness versus completeness (Fleischmann and Wallace 2010).

Honesty versus obedience involves the choice modelers had to make in terms of giving the most accurate answer versus the answer desired by the client. Modelers who follow the creed of “the customer is always right” run the risk of violating the ethical codes of their profession, while those who follow the creed of “honesty is the best policy” may risk losing (some) clients. This value conflict arose most frequently in the corporate laboratory (Fleischmann and Wallace 2010).

Innovation versus reliability involves the inherent conflict between modelers as scientists and modelers as technicians. The incentive structure for scientists revolves around doing things differently in a quest to learn new things, often at the cost of reliability, usability, or other markers of technical success. In contrast, the incentive structure for technicians involves making sure that things work, typically to enable the work of others. Computational modeling can either be bleeding edge or quite robust, but rarely both. This value conflict arose most frequently in the academic laboratory (Fleischmann and Wallace 2010).

Timeliness versus completeness, related in some ways to the two conflicts above, involves the competing pressures to finish a job on schedule or to be thorough in one’s work. Obviously, neither extreme is particularly productive, as something that is extremely timely but also very incomplete is not particularly useful and can instead be quite misleading and even dangerous; on the other hand, it is possible to tweak and refine a model to the point that it is never actually put into use. Most people can agree both that “haste makes waste” and that “perfect is the enemy of good.” However, exactly where one draws that line varies tremendously, based on contextual factors and individuals’ different valuations of these approaches. This value conflict arose most frequently in the government laboratory (Fleischmann and Wallace 2010).

Conflicts in Models as Products

Salient value conflicts connected to models as products include the goals of the product versus the goals of the organization, publication versus customer needs, and listening to clients versus listening to users (Fleischmann and Wallace 2010).

Conflicts of the goals of the product versus the goals of the organization are most likely in an organization with strong top-down directives. For example, the goal of a product designer might be to maximize effectiveness subject to a budget constraint, whereas the organization seeks to produce the cheapest product subject to an acceptable level of effectiveness. In this way, the degree of autonomy (or the lack thereof) experienced by modelers can become embedded in models as products. This value conflict arose most frequently in the corporate laboratory (Fleischmann and Wallace 2010).

Modelers who follow the creed of “the customer is always right” risk violating the ethical codes of their profession.

Publication versus customer needs is related to the value conflict of innovation versus reliability. Choosing an off-the-shelf model is more likely to result in a reliable product, but unlikely to yield a significantly innovative product that can allow the modelers to publish. Further, publication requires significant time and effort, and this time may be taken away from addressing customer needs. This value conflict arose most frequently in the academic laboratory (Fleischmann and Wallace 2010).

Listening to clients versus listening to users involves the inherent value conflicts among the various stakeholder groups involved in the modeling process. Listening to those affected could also be a consideration, but in the modeling contexts that we studied the emphasis rarely progressed beyond the client and/or user. One salient example of this client/user conflict was the confusion and frustration experienced by some of the computational modelers in the corporate laboratory. The modelers, tasked by their clients with building models to create efficiencies and reduce workforce needs, were vexed that users were unwilling to participate in design efforts to this end. This example
demonstrates the importance of modelers' efforts to consider the perspectives of all stakeholders in the modeling process—not just the clients but also users and those affected. While this conflict was common in the corporate laboratory, it arose most frequently in the government laboratory, which had a very hierarchical structure that resulted in significant power distances among stakeholders (Fleischmann and Wallace 2010).

**Values That Reduce Conflicts**

We analyzed the survey data and identified 11 values that were positively correlated with a reduction in value conflicts (Fleischmann et al. 2011a). We used three questions to ask about value conflicts between the modeler’s organization and the three stakeholder groups (clients, users, and those affected):

1. What values are positively or negatively correlated with value conflicts with clients?
2. What values are positively or negatively correlated with value conflicts with users?
3. What values are positively or negatively correlated with value conflicts with those affected by models?

---

**Modelers who valued equality experienced fewer value conflicts among diverse stakeholder groups.**

The value of equality was statistically significantly correlated with the responses to all three questions, indicating that modelers who valued equality experienced fewer value conflicts among these diverse stakeholder groups (Fleischmann et al. 2011a).

Other values identified as statistically significant in one or two of the pairings were a spiritual life, a world at peace, devout, forgiving, honoring of parents and elders, humble, politeness, responsible, self-discipline, and true friendship. We were not able to identify any values that were negatively correlated with a reduction in value conflicts (Fleischmann et al. 2011a).

Modelers who highly valued equality and other values were less likely to observe value conflicts between their organization and other stakeholder groups, although based on the data it is not clear whether these values actually helped them to reduce value conflicts or simply made them oblivious to them (Fleischmann et al. 2011a). Based on our interview data, we are inclined to conclude the former, at least in many cases, as obliviousness to value conflicts appeared to occur most frequently among the least egalitarian modelers (Fleischmann and Wallace 2010).

**Transparency**

Using the literature on value-sensitive design, Friedman and Kahn (2008) identify 12 human values with ethical import: human welfare, ownership and property, privacy, freedom from bias, universal usability, trust, autonomy, informed consent, accountability, identity, calmness, and environmental sustainability. Our study identified another important value, transparency (Fleischmann and Wallace 2009).

Transparency can be seen as a component of informed consent, as users must understand how a system works to actually achieve autonomy in cases where they are given a choice. However, transparency goes beyond cases in which a user is asked to decide something; the user may want to understand how something works even if he is powerless to influence what is done as a consequence. For example, investors may want to understand the workings of the financial markets even though their particular contribution is too small to have any noticeable effect on the market (Fleischmann and Wallace 2009).

**Reasons to Make Models Transparent**

We identified three reasons for making models transparent: political, economic, and legal. The political dimension largely revolves around reducing power inequities and avoiding technocratic situations where the end user is at the mercy of the modeler (to say nothing of those affected, who again may not even be aware that a model is being used). Transparency can have economic benefits, insofar as it may promote customer satisfaction, and in some cases it may reveal corruption in an organization that might otherwise go undetected. Modelers also reported that transparency can be a legal requirement, when there is a need to explain the basis for decisions (Fleischmann and Wallace 2009).

**Ways to Make Models Transparent**

Building on Willemain (1995), we identified five ways that modelers can make models transparent:

1. Transparency should be considered early in the design of the model.
2. The modeling paradigm is important, as some paradigms lend themselves better to transparency (e.g., Bayesian models) than others (e.g., neural networks).

3. Transparency should lead to better understanding, not just a data dump. As a literal example, making the shell of a computer transparent is unlikely, by itself, to teach the average user anything meaningful about how the computer works.

4. Transparency is critical in the evaluation of the model, especially if it is done by someone other than the modeler or there is a goal (or need) to achieve accountability.

5. Transparency is obviously critical when the model is released into the world, in relation to the three reasons for transparency cited above (Fleischmann and Wallace 2009).

Because transparency often comes into conflict with other values, such as accuracy, we designed a teaching case based on this conflict. In the context of an imagined future mission to Mars, modelers (in training) must make a choice between a model that is 99 percent accurate but a black box or 95 percent accurate but transparent. Someone who values autonomy would likely favor the transparent model, as it would empower the user to determine when the model might be inaccurate, while someone who values paternalism might prefer to ensure that the user blindly puts their trust in the most accurate model (Fleischmann et al. 2011c).

Professional Codes of Ethics

In the computing professions, codes of ethics typically serve as vehicles for socialization and education rather than rigid rules that enforce compliance (Anderson et al. 1993). To better understand how modelers themselves perceive codes of ethics, we asked them about their awareness of, familiarity with, and adherence to codes of ethics (Fleischmann et al. 2017).

Values that Correlate with Ethics Code Awareness, Familiarity, and Adherence

We found nine values that correlated with awareness of a code of ethics; only freedom was negatively correlated, while the other eight were positively correlated. Similarly, for familiarity with codes of ethics, ten values were correlated, with nine positively correlated and freedom, again, negatively correlated. Finally, for adherence to codes of ethics, 13 values were correlated, all positively; the most significantly correlated were equality ($p < 0.001$) and social justice ($p < 0.001$) (Fleischmann et al. 2017).

Thus only those who valued freedom were less likely to be aware of or familiar with codes of ethics, while those who valued equality and social justice were particularly likely to adhere to codes of ethics. This finding appears to be in keeping with the motivations for codes of ethics (Fleischmann et al. 2017).

Thematic Analysis of Interview Data

Our thematic analysis of the interview data shed further light on the quantitative findings. One of the two orthogonal dimensions of the Schwartz (1994) Value Inventory ranges from self-enhancement to self-transcendence. One modeler asserted that following a code of ethics was best for both the modeler and everyone else, an observation that helps to explain why we found that positive attitudes toward and experiences with codes of ethics were positively correlated with both self-enhancement values (e.g., authority, preserving my public image) and self-transcendence values (e.g., equality, social justice) (Fleischmann et al. 2017).

Codes of ethics should be bottom-up rather than top-down, to better reflect modelers’ perspectives and experiences.

The thematic analysis also supported (1) Mason’s (1994) covenants with reality (i.e., represent the problem with as much fidelity as possible) and values (i.e., suggest improvements for the client that adhere to the client’s values), and (2) our covenant with transparency (Fleischmann and Wallace 2005) by ensuring that models are opaque to all stakeholders (Fleischmann et al. 2017).

Another important theme was that codes of ethics should be bottom-up rather than top-down, to better reflect the perspectives and experiences of modelers in general (Fleischmann et al. 2017).

Based on our analysis, we conclude that individuals who value universalism and benevolence have a duty to advocate for awareness of, familiarity with, and adherence to codes of ethics (Fleischmann et al. 2017).
Conclusions
Modeling carries important ethical implications for research, education, and applications (Wallace and Fleischmann 2015). Gaps in the transparency of computational models (at least for the general public), for example, can inflame controversies surrounding scientists’ use of them.

A prominent instance of such controversy was “Climategate,” which involved the illegal release of email exchanges among climate scientists working at the University of East Anglia (Martin 2014). The climate change debate is politically fraught, and the media and the public misunderstood (or, in some cases, likely misrepresented) the scientists’ exchange, which was difficult to counteract given the difficulty of making climate change models understandable to the general public.

Computational modelers must be aware of the important societal role of their models, whether they are used for officiating tennis matches or formulating policy recommendations that can shift national and international energy policies. A model necessarily abstracts and reduces from reality, and is the product of a complex process including the modelers as well as (potentially) other stakeholders. Thus, the goal is not to have a “perfect” or “value-free” model—no model of a natural system can completely, perfectly capture the complexity of reality—but rather to be as transparent as possible about both the modeling process and the (known and potential) limitations of the model relative to reality.

The overall argument here is not that modelers should be better people. Although it is certainly important to attract people of strong character to the modeling profession and to reward and retain these individuals, it seems likely that the vast majority of modelers do have the explicit intent of making the world a better place through their work. (And in any event, it is challenging to deter would-be troublemakers from causing ill through their models, particularly given the lack of enforceability of codes of ethics.)

The critical challenge is to ensure that modelers consider design decisions from multiple perspectives, so that they not only take account of their own values but are sensitive to those of their users (Friedman et al. 2006; Friedman and Kahn 2008). Educational interventions can be effective in achieving this goal, such as multirole interactive cases that illustrate the interconnectedness and interdependency of ethical decision making (Fleischmann et al. 2009, 2011c,d,e).

Engineers in general, and modelers in particular, need to appreciate diversity of perspectives and ensure that they are not practicing technological somnambulism (Winner 1986). They must be aware of the ethical implications of their decisions and ensure that they are enabled and empowered to make conscious choices rather than acting by default (Fleischmann 2010, 2014).

Acknowledgments
This material is based in part on work supported by the National Science Foundation under grant nos. 0521834, 0646404, 0731717, and 0731718. Thanks go to Justin Grimes, Cindy Hui, Adrienne Peltz, and Clay Templeton for their help with data processing for the publications cited and discussed here, as well as all of our anonymous participants who generously donated their time to further this research. Thanks also go to Deborah Johnson and Gerry Galloway for their helpful advice and feedback on earlier drafts.

References
American Society for Information Science and Technology, Milwaukee.


Corruption in engineering/construction is an important problem that national and international resources are available to combat.

William P. Henry, PE, is a past president (2005) of the American Society of Civil Engineers.

Estimates indicate that more than $500 billion is lost to corruption each year in the global engineering/construction (E/C) industry. While this economic loss is staggering, it pales in comparison to the losses suffered by people in need of water and wastewater projects, roads, schools, hospitals, and residences to improve their lives. Moreover, corruption kills people when projects are poorly constructed, and it reduces funds for needed infrastructure projects.

Corruption reduces the number of projects that are built and compromises the safety of those that are, and is therefore incompatible with sustainable development. Because engineers hold paramount the health, safety, and welfare of the public and support the principles of sustainable development, they must work to eliminate corruption from the E/C industry.

To that end, a constant dialogue is needed among engineers on ethical issues, and it should match the time spent talking about technical issues, safety, costs, and deadlines. For such discussion to be meaningful and effective, engineers need a common vocabulary on the subject.

Vocabulary of Corruption

Ethical behavior is the goal, but many engineers don’t have the vocabulary needed to discuss it. It may help to define components of the opposite of ethical behavior—corruption—to provide needed vocabulary.
Merriam-Webster (www.merriam-webster.com) defines corruption as the “impairment of integrity, virtue, or moral principle,” “inducement to [do] wrong by improper or unlawful means,” and “dishonest or illegal behavior especially by powerful people.” The latter includes the misuse of official power for personal gain.

In the E/C industry, corruption takes a variety of forms because there are so many types of organizations involved in projects:

• public owners
• private owners
• engineers
• constructors
• lenders
• material suppliers
• equipment suppliers
• regulatory/permitting agencies.

There are numerous possible interrelationships among these parties and corruption requires only two individuals to act together in an unethical manner, so myriad potential interactions can result in corruption during the procurement and/or execution phases of an E/C project. The main forms of corruption are

• kickbacks and bribery
• front companies
• bid rigging and collusion
• conflicts of interest
• fraud
• money laundering.

Any and all of these can occur on any project.

Kickbacks and Bribery
Kickbacks and bribery are two sides of the same coin. A kickback is a demand for payment by someone in a position of authority in return for a decision favorable to the prospective payee. Bribery is an offer to pay someone in a position of authority to make a decision favorable to the offeror.

The person in the position of authority seeking a kickback may be a purchaser (a government official, private owner, or purchasing agent buying materials, equipment, engineering services, or construction services); engineer, constructor, or supplier selecting subcontractors; lender making a decision to lend to a given owner; or regulator in charge of permitting or inspection decisions.

The person offering a bribe may be an engineer, constructor, material or equipment supplier (seeking business, permits, or inspection approvals), or owner seeking funding. In a recent case two senior executives of Louis Berger, a New Jersey–based construction management company, were sentenced to prison in July 2016 for bribing officials in India, Indonesia, Vietnam, and Kuwait in order to secure government contracts (USAO–New Jersey 2016).

Two senior executives were sentenced to prison in July 2016 for bribing officials in four countries in order to secure government contracts.

Bribes can be direct payments or “political contributions,” known as “pay to play” payments, which keep qualified, ethical firms from obtaining work. In April 2016 three executives from Birdsall Services Group received prison sentences, fines, and disbarments for a scheme in which their employees made political contributions in New Jersey that the firm then reimbursed to the employees (OAG–New Jersey 2016).

By far the biggest fine for bribery—$1.34 billion—was levied by the US Department of Justice and Germany against Siemens AG for paying more than $100 million in bribes to the Argentine government in order to secure a $1 billion contract (Lichtblau and Dougherty 2008).

There are opportunities for kickbacks and bribery on all projects in all countries.

Front Companies
A front company is established in secret by a corrupt owner or staff to provide little service to a project while being paid substantial fees. It often serves as a local agent, providing services on an international project so it does not have to produce substantial work products.

A front company is usually a new company that has no available track record and offers a variety of unconnected services. Although these traits are also common
among legitimate joint venture companies, the biggest difference is the availability of ownership records. A front company has few records of ownership because the owners do not want to be known; a legitimate joint venture has clear, open ownership records.

Bid Rigging and Collusion
Bid rigging and collusion can be accomplished by all members of an E/C project team—the owner, engineer, constructor, lender, supplier, or regulator.

Owners can rig bids by, for example, setting extremely short bid periods so that only the firms they illegally prenotify will be able to submit detailed, responsive bids, or by excluding qualified firms from bid lists that include only “favored” firms.

After contracts have been signed, collusion may involve deals between the owner’s and constructor’s personnel. For example, the owner’s staff may approve unjustified project modifications or change orders that raise the contractor’s revenue, lower its cost, or both, in exchange for compensation.

Constructors and suppliers may engage in bid rigging and collusion by agreeing among themselves which firm will get the contract on each of a series of projects. On each project, the agreed-upon winner submits an artificially high bid, and the others submit even higher bids. This gives excess profits to firms and reduces the funds available for other projects.

Bid rigging and collusion can also be parts of more complex corruption schemes.

Conflicts of Interest
All types of conflicts of interest are forms of corruption. The most obvious conflicts involve decision makers who get direct personal gain from their decisions on a project. Less obvious conflicts of interest involve the decision maker’s friends or family members who get the direct personal gain from a decision. All participants in a project have the potential for conflicts of interest.

Fraud
There are many opportunities for fraud in E/C projects; some of the most common fraudulent acts are

- embezzling funds from project accounts
- taking vehicles, computers, other project equipment or materials for personal use
- using project funds, equipment, and/or materials for nonproject uses such as building or remodeling a house or taking a vacation
- selling project equipment or supplies for personal profit
- setting up employment and collecting paychecks for “ghost employees”
- substituting lower-quality materials or equipment than specified in the contract, while billing at the contract prices
- billing employees at rates higher than called for in their pay grades
- falsely claiming Disadvantaged Business Enterprise (DBE) status.

In August 2016 Larry Davis, an executive with DCM Erectors Inc. that received nearly $1 billion in contracts to rebuild the World Trade Center in New York City, was convicted of wire fraud and conspiracy in Federal District Court in Manhattan (USAO–Southern District of New York 2016). His fraudulent behavior involved claiming that people were owners of qualified DBE firms when they were not.

In 2013 the Justice Department recovered nearly $3 million from TesTech and its owner Sherif Aziz, and CESO and its owners David and Shery Oakes, for falsely claiming DBE status on federally funded transportation projects in Ohio (USDOT OIG 2014).

Opportunities for all types of fraud are open to all project participants.

Money Laundering
Money laundering involves taking illegally obtained money (e.g., from bribes or kickbacks) and channeling it into legal businesses such as a construction company. The company’s revenue and expenses can be overstated and the resulting profit appears to be legitimate.
In March 2016 in Brazil, Marcelo Odebrecht, president of Odebrecht Construction, was sentenced to 19 years and 4 months in prison for corruption and money laundering (Dickerson et al. 2016).

Training is needed to ensure that all engineers fully understand the terms presented above, so that they recognize the behaviors and can communicate about corruption and related activities.

Tools and Programs to Promote Ethical Behavior

Corruption and projects can go together like summer and heat or winter and cold. But just as an individual can don appropriate clothing for heat or cold, an engineer can make sure that a project “dons” the appropriate protective gear to thwart corruption. Protective measures include management systems that are open, transparent, and implemented throughout the project, as well as a project team culture in which all engineers know the potential for corruption on the project, the actions they must take if they find it, and overall expectations of ethical performance.

Practical, economical, and successful personal training and management systems that prevent corruption on projects, and the organizations that developed them, are identified below.

Professional Societies

Most local, national, and international professional societies have adopted codes of ethics that guide their members toward acceptable actions and behavior on projects. Many also provide articles on unethical situations in their publications and have hotlines for members to discuss troublesome project situations.

The members of all these societies are individuals, not companies or agencies. The societies therefore offer materials and opportunities that focus on the individual engineer, including training in avoiding and dealing with corruption, and opportunities for networking with others from different parts of the E/C industry and from different countries.

The American Society of Civil Engineers (ASCE; www.asce.org) offers resources that address good management as well as ethical behavior. Its continuing education department delivers technical, management, and ethics seminars and webinars.

The ASCE Code of Ethics, amended in 2006 to more strongly address corruption, gives strong guidance on ethical practice to all ASCE members and presents the elements needed for a strong anticorruption culture. Canon 6 of the Code of Ethics reads:

Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the engineering profession and shall act with zero tolerance for bribery, fraud, and corruption.\(^1\)

It further stipulates the following Guidelines to Practice:

a. Engineers shall not knowingly engage in business or professional practices of a fraudulent, dishonest, or unethical nature.

b. Engineers shall be scrupulously honest in their control and spending of monies, and promote effective use of resources through open, honest, and impartial service with fidelity to the public, employers, associates, and clients.

c. Engineers shall act with zero tolerance for bribery, fraud, and corruption in all engineering or construction activities in which they are engaged.

d. Engineers shall be especially vigilant to maintain appropriate ethical behavior where payments of gratuities or bribes are institutionalized practices.

e. Engineers should strive for transparency in the procurement and execution of projects. Transparency includes disclosure of names, addresses, purposes, and fees or commissions paid for all agents facilitating projects.

f. Engineers should encourage the use of certifications specifying zero tolerance for bribery, fraud, and corruption in all contracts.

In addition, ASCE’s publication Leadership and Management in Engineering devoted an issue to Addressing Corruption in Our Engineering/Construction Industry (Henry 2009).

---

1 The ASCE Code of Ethics is available at www.asce.org/code-of-ethics.
At the international level, a number of global or regional societies are active in addressing corruption. Engineers Australia (EA) has been active in revising the country's National Code of Practice for the Construction Industry (www.fwbc.gov.au). Firms working on government-funded projects there must be in compliance with the code, including all its provisions for ethical behavior. And the World Federation of Engineering Organizations (WFEO; www.wf eo.org), Asian Civil Engineering Coordinating Council (ACECC; www.acecc-world.org), and Pan American Union of Engineering Societies (UPADI; http://upadi.com) each has a standing anticorruption committee that holds annual meetings to share information and leads workshops on addressing corruption on projects.

More than 140 companies from 39 countries have agreed to Principles for Countering Bribery, based on integrity, fairness, and ethical conduct.

Constructors

In 2005 the firms in the E/C section of the World Economic Forum launched the Partnering Against Corruption Initiative (PACI), a private sector, supply-side initiative to establish multi-industry principles and practices to eliminate corruption in project procurement and performance. More than 140 companies from 39 countries have agreed to the PACI Principles for Countering Bribery, which are based on integrity, fairness, and ethical conduct. The chief executive officer of each participating company pledges, in writing, to

1. commit the company to a zero-tolerance policy for bribery, and

2. implement a strong, active anticorruption program to guide the behavior of the company's employees.

Consulting Engineers

Consulting engineering firms, through the International Federation of Consulting Engineers (FIDIC; http://fidic.org), have developed strong anticorruption programs for engineering and procurement activities with their Business Integrity Management System (BIMS) and Government Procurement Integrity Management System (GPIMS).

FIDIC uses the term “integrity management” because (1) ethical integrity is needed to fight corruption and (2) a strong management system is needed to control a firm's activities and verify its ethical performance. BIMS provides management documents and examples for companies, and is tailored to a firm's engineering units; it can be independently verified as an ISO 9000 management system (more on the ISO below). GPIMS is tailored to an organization’s procurement units.

Construction Observers

Transparency International (TI; https://www.transparency.org), a long-time observer of the global E/C industry, has developed business principles, guidelines, and implementation and verification plans for countering bribery, as well as a Corruption Perceptions Index, which rates the openness of a country's decision-making processes. The more open the process, the less risk of corruption. According to the TI Bribe Payers Index of 2011 (www.transparency.org/bpi2011), public works and construction were the most corrupt industry sectors.

TI’s Project Anticorruption System (PACS) has standards and templates that target bribery and fraud through independent monitoring, due diligence, contract terms, procurement requirements, government commitments, corporate programs, programs for individuals, training, reporting, and enforcement. PACS has been distributed to TI national units, engineering and construction associations, banks, and governments.

Lenders

Major international lenders—such as the World Bank, African Development Bank, Asian Development Bank, Inter-American Development Bank, European Investment Bank, European Bank for Reconstruction and Development, and International Monetary Fund—have standardized their approaches for dealing
with corruption. They are also developing proposals to assist countries in combating corruption by providing information about changes governments can make in project procurement procedures and about the roles and activities of regulatory and permitting agencies. Checking on how a government agency does business is always part of complete due diligence.

**Standards Organizations**

On October 15, 2016, the International Standards Organization (ISO) adopted an antibribery standard (ISO 37001), a management system standard that can complement the standards for quality (ISO 9001), environment (ISO 14001), and safety (ISO 18001). All of these standards need to be included in all project contractual requirements.

ISO 37001 replaced the British Standards Institute (BSI) Standard 10500, the antibribery standard that BSI adopted in 2011. And the American National Standards Institute (ANSI) supports the adoption of ISO 37001.

**Independent Industry Groups**

The Global Infrastructure Anti-Corruption Center (GIACC; www.giaccentre.org) was founded in 2008 by two experienced construction attorneys in England. The independent, nonprofit organization promotes implementing anticorruption measures in managing companies, agencies, and projects. Its approach to managing corruption is similar to the ways safety, quality, and risk are controlled: through procedures, training, monitoring, and enforcement. It led the development and adoption of ISO 37001 and BSI 10500.

The center’s website has a wealth of useful information, including descriptions and examples of corruption that are useful for vocabulary and training exercises; examples of anticorruption programs suitable for agencies, companies, and lenders; a complete project anticorruption system designed to prevent and detect corruption on projects; and an array of anticorruption tools, including

- sample contract terms
- a corporate code
- due diligence procedures
- sample employment terms
- gifts and hospitality policy
- reporting requirements
- training needs and programs
- ideas for achieving transparency in an organization.

The GIACC website also provides materials for starting an anticorruption program or for benchmarking an existing program against others. Of particular use is the information on due diligence, covering the laws of the country of the project, confirmation that the project is necessary and conceived for a legitimate purpose, the owner's history, potential business partners, and contract terms to help ensure that corruption will not be part of a project.

Another resource, the Anti-Corruption Education and Training (ACET) program, was created by international participants in the E/C industry to provide good ethical training for practitioners (and students). The ACET team raised funds, hired a writer and producer, and, with them, developed the script for a 42-minute DVD drama, *Ethicana*, depicting corruption in the procurement and production of a project. The complete *Ethicana* package contains the DVD, classroom materials, trainer materials, and a “train the trainer” module.

ACET’s *Ethicana* resources reinforce the vocabulary needed for dialogue about anticorruption and present situations that both procurement and project staff may face on projects. The situations depicted were developed from the actual experiences of the ACET team members.

After reviewing situations in a classroom, and discussing them with senior personnel and peers, engineers are better able to handle ethical issues in their work. *Ethicana* shows why engineers should act ethically while following an anticorruption program that tells them what to do. It has been successfully used to train engineers in more than 20 countries on six continents.
Summary

E/C projects are vital to the people for whom they are built, and important to agencies in implementing their mission as well as lenders and firms to keep their business thriving. All indications are that there will be more global projects in the future than ever before. Many are forecast in developing countries where corruption has been systemic. It will take vigilance and ongoing management attention to keep corruption at bay on all projects in all countries.

The two most effective tools for ethical practice are

1. a project culture founded on ethics, embraced by all levels of staff and management, and communicated to all project team members and business partners; and
2. strong management systems that start from the highest echelons of the organization and whose implementation is regularly verified throughout the organization.

For the first tool to be effective, all employees must be able to talk with a common, well-understood vocabulary. The importance of this vocabulary cannot be overstated—it is the cornerstone of the ethical component of a project, the difference between people talking with each other versus talking past each other. It enables regular discussions on ethics among engineers, between engineers and managers, and among managers.

For the second tool to be effective, organizations must have anticorruption systems that clearly demonstrate a strong conviction to keep corruption away from projects. Such systems are the day-to-day guardians against corruption. If they are in place, it is wise to benchmark them against what others are doing; if they are not, now is the time to develop and implement them.

There are many sources of information on effective anticorruption systems, which can be developed in stages. The important thing to remember is that these systems are only words on paper unless they are implemented with top-down authority and their continuous use is verified on a regular basis.

Anticorruption materials, guidelines, and training programs give real-life meaning to the words through realistic examples of corruption. These materials can make corruption less likely to occur on every project.

Acknowledgments

This article is dedicated to the memory of Arthur J. Fox, the ASCE president in 1976 who contributed so much to the society’s current anticorruption initiatives and was instrumental in the success of the ACET program that produced and distributed Ethicana.

The contents of this paper have been developed over the past 12 years, during which I have been active in addressing corruption in the E/C industry. Its contents come from interactions with leading engineers, constructors, lenders, NGO leaders, and attorneys. Members and staff of the American Association of Engineering Societies (AAES), ASCE, FIDIC, PACI, EA, GIACC, WFEO, and, most recently, the Pan American Academy of Engineering (API) have added important ideas. If I were to name all from whom I learned, the list would be longer than this article. They all have my thanks for their efforts to address corruption in the E/C industry.

References


Engineering ethics education increases the likelihood that engineering students will be prepared to handle ethical issues in their professional lives.

Can Engineering Ethics Be Taught?

Deborah G. Johnson

In 2010, after a two-year inquiry, a judge concluded that Canadian Prime Minister Brian Mulroney had acted inappropriately when he accepted large amounts of cash from a German-Canadian arms lobbyist. The judge suggested that all public servants should get ethics training. Peter Worthington (2010), a columnist for the Toronto Sun, responded to this suggestion in the following way:

[A] case can be made that “ethics” are something that you either have, or you don’t have. Or, to put it slightly differently, ethics are a code you subscribe to or choose to ignore for reasons of personal interest. All the training, teaching, studying, reading, or lectures in “ethics” will not make a person more ethical if he or she does not have these core values to begin with.

Worthington expresses a skepticism that is not uncommon when it comes to teaching ethics to undergraduate engineering students, as a professor of engineering observed (Stephan 2004, p. 5):

Some years ago I argued with a fellow professor about the issue of engineering ethics education at the college level. His point was along the lines of, “Hell, if eighteen-year-old kids don’t know right from wrong by the time we get ’em, they’re not going to learn it from us.”

This article is based on a chapter from my forthcoming book, Engineering Ethics: Contemporary Debates, to be published by Yale University Press.
Despite such skepticism, most undergraduate engineering programs in the United States (and in many other countries) require some type of training in ethics as part of the curriculum. This may be due in part to the fact that ABET requires it for program accreditation.

ABET specifies outcomes that engineering students must achieve by the time they graduate, and one of those outcomes is “an understanding of professional and ethical responsibility” (ABET 2014, p. 3). The agency leaves it up to individual programs to decide how they will achieve this, but during periodic ABET reviews each program is required to demonstrate how it achieves the outcome.

If the skeptics are right, the ABET requirement is a waste of time. The answer to the important question of whether ethics can be taught is far from simple and depends on what is meant by “ethics training” and what is meant by “ethical engineers.” The following discussions illustrate both.

**Can Ethics Be Taught?**

The question isn’t whether engineers make moral decisions (they do!), but whether and how ethical decision making can be taught. Skepticism about the possibility of teaching ethics takes multiple forms.

**Ethics as Inborn Predisposition or Reasoning Skill?**

Some skeptics believe that a predisposition to ethical or unethical behavior is inborn, others that such a predisposition is a function of early childhood training. Either way, skeptics tend to think that the predisposition cannot be changed by education or that it can be changed only by powerful experiences. Some think that, regardless of predisposition, an individual’s behavior can be brought in line by threats of punishment for unethical conduct. Implicitly, skeptics seem to believe that ethical behavior is not a matter of reasoning or reflection but something more primitive.

By contrast, the standard approach in ethics education is to focus on ethical reasoning and to try to provide students with information, ideas, and experiences that will develop their ethical reasoning skills. The idea is that improving such skills will inform moral behavior. With the goal of improving moral reasoning, many ethics courses focus on ethical theories such as utilitarianism, deontology, and virtue ethics as tools or heuristics for improved ethical reasoning.

**Moral Intuitions**

The focus on ethical reasoning has been criticized as misconceiving how individuals make moral decisions. Critics claim that ethical decision making is based on moral intuitions, not reasoning. This constitutes another form of skepticism about teaching ethics because if individuals make moral decisions on the basis of intuitions, then teaching them how to reason about ethics may do no, or little, good.

Moral intuitionists (also called social intuitionists because they believe moral intuitions are interpersonal) claim that examination of how people actually make moral decisions reveals that intuitions play a much larger role than previously thought. Indeed, moral intuitionists argue that reasoning comes in only after intuitions, and that it is more like rationalization: used to explain and justify what one’s intuitions tell one to do. Jonathan Haidt (2001, p. 817) put it succinctly:

> The central claim of the social intuitionist model is that moral judgment is caused by quick moral intuitions and is followed (when needed) by slow, ex post facto moral reasoning.

Moral intuitionists note that individuals are spontaneously repulsed by certain kinds of behavior. For example, without reasoning, individuals find incest or the torture of children abhorrent, and for some the thought of eating animals is viscerally repugnant.

**Moral Reasoning**

Moral reasoning theorists argue that moral intuitions don’t come out of nowhere; reasoning comes into play as individuals form their moral intuitions through developmental processes that involve reason.

Another argument against moral intuitionism points to evidence of individuals reasoning about difficult situ-

---

1 Utilitarianism focuses on the consequences of choosing an action or policy. Deontology is the study of the nature of duty and obligation. Virtue ethics emphasizes moral character.
ations, such as deciding whether to have an abortion or to join the military during a controversial war (Pizarro and Bloom 2003).

Moreover, there is evidence that reasoning can lead to a change in one’s moral intuitions. For example, through discussion and debate with a friend one might be convinced to become a vegetarian, or one might through reflection decide to refrain from telling jokes that perpetuate racial or gender stereotypes. Critics of moral intuitionism also note that individuals frequently encounter ethical dilemmas for which there are no already formed intuitions.

This is a thorny debate that goes to the heart of what is going on internally when a person makes a moral decision. The debate has deep historical roots in philosophy, going back to Plato. Is reason a slave to the passions? Or are the passions a slave to reason? Much of engineering ethics education tends to hedge this debate by addressing both moral reasoning and moral motivation.

These ideas about how people make moral decisions underlie and influence the most important questions in engineering ethics education: What are the goals of engineering ethics education? How can they be achieved?

The Goals of Teaching Engineering Ethics

In the burgeoning literature on engineering ethics education (and professional ethics education more broadly) the focus is on what can and should be taught and how best to teach it. The following four goals guide most programs in one way or another:

- Make students aware of what will be expected of them in their work as engineers.
- Sensitize students to ethical issues that might arise in their professional practice.
- Improve students’ overall ethical decision making and judgment.
- Motivate and even inspire students to behave ethically.

Needless to say, these goals are not mutually exclusive.

Knowledge of Codes of Professional Conduct

Knowledge of the standards and expectations for practicing engineers cannot possibly be inborn, learned in early childhood, or intuitive, but such knowledge is critical to being an ethical engineer.

At a minimum, engineers need to know that there are professional codes of ethics and standards of conduct. If a new engineer doesn’t know what a conflict of interest is or that accepting gifts from contractors may lead to accusations of bribery and corruption, he is much more likely to slip into these forms of unethical behavior.

The challenge is to ensure that students not only are aware of codes of ethics and standards of behavior but know how to interpret and apply them. Some argue that simply knowing what codes of conduct say doesn’t help engineers in real-world situations because the statements in codes must be interpreted in each particular situation (Eriksson et al. 2007).

Simply knowing that a code of ethics exists and what it says is not sufficient to help an engineer figure out what to do.

For example, many engineering codes of ethics specify that engineers should act faithfully on behalf of their clients. Imagine an engineer who discovers a safety problem while working on a client’s building. The safety problem could affect people who work in the building by, say, increasing the risk of exposure to toxins. Suppose the engineer tells her client and the client asks her to keep quiet about the safety issue because the client is planning to sell the building.

Although codes of ethics make it clear that engineers have a responsibility to their clients, they also specify that engineers should “hold paramount the safety, health, and welfare of the public.” In this situation, simply knowing that a code of ethics exists and knowing what it says is not sufficient to help the engineer figure out what to do. Even if she recognized that the safety of the public comes first, it is unclear what action she ought to take. Engineering educators therefore suggest that students be given opportunities and experience in interpreting codes of conduct and applying them to real-world situations. In this hypothetical example, had the engineer engaged in discussion and reflection about the meaning of fidelity to clients during her education, she might more readily come to the conclusion that she should go back to the client and explain why some action should be taken before the
client sells the building or at least explain to the client the full consequences of not informing potential buyers about the problem.

Some argue that there is a danger in exposing students to codes of ethics without practice using them or grappling with their interpretation. The fear is that such exposure without practice will lead students to think legalistically. Law and ethics are not the same. Legalistic thinking may suggest that one should simply follow the rules without thinking about dimensions of engineering work that aren’t covered by law.

One answer to those who are skeptical about teaching engineering ethics is, then, that—whatever character student engineers already have—activities that (1) make them aware of codes of ethics and standards of behavior and (2) develop their skill at interpreting and applying the codes and standards increase the likelihood that they will respond more thoughtfully and in a professional manner to difficult situations they encounter in their practice.

---

**Engineers can go wrong simply by not recognizing that a situation involves some form of unethical behavior.**

---

**Awareness and Ability to Identify Ethical Issues**

Engineers can go wrong simply by not recognizing that a situation involves another person’s rights, undermines professional integrity, creates a conflict of interest, or engenders some other form of unethical behavior. Imagine an engineer not realizing that there is anything problematic about reviewing construction plans submitted by a close relative, or failing to see where a romantic relationship at work may lead.

Engineering ethics educators frequently use case studies to raise awareness of ethical issues and sharpen students’ ability to identify ethical issues. Exposure to case studies—whether real incidents or fictitious situations—increases the likelihood that a new engineer will identify an ethical issue quickly or early on before getting into too much trouble. Familiarity with case studies is effective because it draws on a basic human capacity for pattern recognition (Abaté 2011): students ascertain patterns that they can then recognize in their own real-world experiences.

Another approach teaches students moral frameworks and concepts such as integrity, loyalty, respect, and conflict of interest, so that they will be more likely to recognize situations in which these concepts are relevant. For example, when one understands the concept of never treating a person merely as a means, one is more likely to notice when someone is being treated that way. Ethical concepts and theories provide a language and a way of looking at the world that enable individuals to see what they might otherwise not have noticed.

Thus another answer to the skeptics is that, in order for engineers to behave ethically, they have to learn to identify ethical issues and to recognize that circumstances or situations in which they find themselves have ethical dimensions.

**Moral Reasoning/Improved Decision Making**

The ability to identify ethical issues is critically important, but what happens after one becomes aware of a situation calling for a moral decision? Depending on the situation, deciding whether to take action and what action to take can be enormously challenging. Hence, developing students’ ability to make ethical decisions is a central focus of engineering ethics education.

Engineering ethics educators are often asked to demonstrate that students’ ethical decision-making skills have improved after they have been exposed to a module or taken a course or had a particular experience. The need for evidence has led some social scientists to develop models to assess ethical decision making. James Rest (1986) is one of the most influential scholars in this area. His model suggests that ethical decision making involves four steps:

1. recognize the moral issue,
2. make a moral judgment,
3. resolve to place moral concerns ahead of other concerns, and
4. act on the moral concerns.

Step 1 was discussed in the previous section, and steps 3 and 4 are treated in the next section. The second step has received the most attention in discussions of engineering ethics education because many believe that moral reasoning and ethical decision making together are a skill that can and should be taught.

Without a doubt, engineers often face situations in which they have to make difficult moral decisions:
• Should I blow the whistle on my employer?
• Should I remove myself from this situation because I may be seen as having a conflict of interest even though I do not?
• Should I let this design proceed to the next level of development even though I know it can’t be made safer?

The standard approach is to give students practice in ethical decision making by engaging them in case or scenario analysis and role playing with opportunities for discussion, feedback, and exposure to alternative perspectives. Students have an opportunity to experience ethical dilemmas and reflect on how to handle them.

Students can learn from reflecting on hypothetical situations calmly, carefully, and with others, before they experience real-world situations when they may be under great pressure and have less opportunity for discussion and reflection. In the classroom students learn, among other things, that the ethical dimensions of a situation can be brought to light through discussion and analysis, and alternative, more strategic responses can be teased out through reflection and discussion.

Ethical decision making is an important part of engineering ethics, and courses that give students the opportunity to consider, reflect upon, discuss, and even debate what to do in tough situations are believed to improve their ethical decision-making skills.

**Motivation**

Importantly, being ethical involves more than making decisions. One has to resolve to act on those decisions—and then do so. Engineering ethics education seeks to inspire and motivate students to behave ethically.

Most people have had the experience of being inspired by a passionate speech, charismatic leader, or personal experience that changed the way they think. Engineering ethics educators therefore expose students to stories of engineers who have made great sacrifices to do the right thing, or taken on noble causes, or withstood pressure to engage in wrongdoing.

William LeMessurier is often put forward as this kind of inspiring figure. He was a distinguished structural engineer and a consultant in the development of an innovative building, the Citicorp Headquarters in New York. When he learned, after the building was completed (in 1977), that it did not meet the safety standards for buildings situated as it was, he acted promptly and responsibly (Pritchard 1998, p. 221):

> He knew how to correct the problem, but only at the cost of a million dollars and at the risk of his career if he were to tell others about the problem. He promptly notified lawyers, insurers, the chief architect of the building, and Citicorp executives. Corrections were made, all parties were cooperative, and LeMessurier’s career was not adversely affected.

Engineering ethics educators have compiled other stories of heroic and exemplary engineers who are less well known than LeMessurier but equally impressive in the way they risked their own well-being to protect the public or a group of people (e.g., Huff and Barnard 2009; Madhav 2014; Pritchard 1998).

**Students can learn from hypothetical situations before they experience real-world situations when they may be under great pressure.**

Another strategy to motivate students is to involve them in service projects such as building a much-needed sanitation system in a small, poor, rural community. Students see the potential of their work to do good and see engineering as an endeavor that can make the world a better place. Engineers Without Borders (EWB) is an organization devoted to providing students with international opportunities of this kind.

Rest’s last two steps—resolve to place moral concerns ahead of other concerns and act—might together be thought of as a form of “moral courage.” Moral courage is the ability to take action for moral reasons despite fear or likelihood of negative personal consequences. Engineers often find themselves in situations in which their work environment makes it difficult for them to express their ethical concerns about safety, negative impacts on vulnerable populations, or the legality of an endeavor. They need moral courage to stand up for and speak out about what they think is the right side of an issue.

For all these reasons inspiring students to want to be ethical engineers is an important part of engineering ethics education.
Conclusion

Can engineering ethics be taught? Skeptics seem to have oversimplistic notions of ethics and of human behavior. To suppose that individuals are born with or learn ethics in their childhood and never learn anything else is to suppose that ethics is simply a matter of learning a few rules and then adhering to them no matter what.

While learning a few basic moral principles early in life is probably a good thing, real-world situations are often complex and require more than simply following rules. For one thing rules need to be interpreted and applied to particular circumstances. For another, real-world situations often involve tradeoffs and prioritizing, and depend on the details of the situation.

Engineering ethics can be understood to involve the following components:

• knowledge (of codes and standards),
• skill (the ability to identify ethical issues),
• reasoning (the ability to make moral decisions), and
• motivation (the will to take action).

All of these can be taught—and thus so can engineering ethics. This does not mean that engineering ethics education can make so-called “bad” people good or ensure that all engineers will always do the right thing, but it increases the likelihood that engineering students will be better prepared to handle the ethical issues that arise in their professional lives.

Finally, it is important to note that the focus here has been on teaching individual engineers, but engineering ethics is not just a matter of individual behavior. Ethical engineering also requires the creation and maintenance of institutions, organizations, and environments that enable individuals to behave ethically and that promote and facilitate engineering endeavors that are good for humanity.

References


Worthington P. 2010. Ethics can’t be taught: They are a code you either subscribe to or choose to ignore. Toronto Sun, June 7. Available at www.torontosun.com/comment/columnists/peter_worthington/2010/06/04/14264071.html.
An Interview with... Sal Khan

RON LATANISION (RML): We are glad to have a chance to talk with you, Sal. I have always felt that education is a means of integrating people into the culture of not only a country but also the world. Given all the things you've done over the past 10 or so years, I am very impressed by the evolution of Khan Academy and your involvement.

SAL KHAN: I appreciate that.

RML: As a starting point, I understand that when you left MIT you began working as a financial analyst?

MR. KHAN: Actually my first job was as a product manager at Oracle. My background was in computer science and math, and my first job was in software. Then I left to do a startup where, at the ripe age of 22, I was the CTO—like any self-respecting 22-year-old in 1999. It did well until Nasdaq popped.

Then I applied to business school, where I took a capital markets class with a professor who was an ex-engineer who became a derivatives trader and then decided to get his PhD in finance and became a professor at Harvard. I had a rapport with him and loved his class—I was kind of the closer for the class. I thought, ‘What in life can I do that is essentially this class?’ He said, ‘You should go work at a hedge fund.’ I said, ‘That sounds great. But what is a hedge fund?’ I talked to some people. I had a lot of student debt so I wanted to know how much do you make at a hedge fund? When I found out I said, ‘Oh, yeah, I am definitely working at a hedge fund.’

RML: I understand you had a cousin who wanted some tutoring in math and you started doing that and that led to what you do now. It’s a pretty big leap from a hedge fund financial analyst to launching an educational enterprise like Khan Academy. How did you get to that point? What was the motivation?

MR. KHAN: The initial motivation was that I have always enjoyed tutoring and math and science and academic knowledge. As a hedge fund analyst I became aware that, no matter what career you choose, there are parts of your brain that you enjoy but don’t get to use. When my 12-year-old cousin was put in remedial math class in 7th grade, I thought, ‘That’s going to follow her through the rest of her life.’ I felt very confident—she is a bright young woman—that with a little help she might be able to do a lot better. I had to help my cousin.

The other motivation was, it’s cool to have a daily connection with your 12-year-old cousin who lives on the other side of the country. I think everyone craves a family connection, especially when you’re by yourself.

And a lot of times the story is Oh, gee whiz, I just happened to fall into this thing. It’s true. Even when I was at MIT, I spent a summer with a fellowship to work on educational software. Many times I had found myself interested in education and the potential for software, in particular, to help scale. I think almost every software engineer has thought about this because most care about education as well as software.

I started tutoring my cousin and in 2–3 months she went from being a remedial student to being the top student in her class. This experience validates that...
famous Benjamin Bloom study, the Two Sigma,¹ about having a personal tutor. Then I started tutoring her younger brothers. Word got around the family, and within a year and a half I was tutoring 10–15 cousins and family friends.

As an engineer I started to think, ‘How does this scale and what parts of this can I create tools for that will help me scale?’ In the beginning my cousins just needed practice. I looked on the Internet, there were some questions here or there, but it was pretty fragmented and of variable quality.

So I started writing questions that were auto-generated and then auto-graded. Then I wanted to see what they were doing so I added dashboarding and tracking. I’m always assigning different questions, so I thought, ‘What if I auto-sign based on what they show proficiency in and what they did not show proficiency in?’ I was falling into this thing.

I was building out a mastery learning system. I did not know that was the name for it at the time, but this is what Benjamin Bloom theorized, and before him there was Carleton Washburne and the Winnetka plan 100 years ago. Many people have already thought of this stuff. I only found out about it when I started doing research for myself.

RML: Did your experience either in EECS at MIT in developing software, for example, or your MBA lead you to think there might be a business model that would be workable to deliver something like this?

MR. KHAN: When I was doing it at the beginning, it was just like a significant hobby. When I started I was based in Boston. The firm I was working for was very small—just me and my boss. We moved out to the Bay Area, in the middle of Silicon Valley with all these people who graduated from MIT or Harvard Business School, all entrepreneurs or venture capitalists.

At first a lot of them wanted to know, What is the business model? How are you going to make money? I said I was just doing this for fun. They sounded very irritated. I said I enjoyed it—“look at this nice letter I got, that makes it worth it.” But once there were several hundred thousand people using it, we started trying to get some press. And some venture capitalists started to reach out and say to me, “I will write a check right now, Sal, and you can work on what you want to work on and it will be a for-profit business.”

I think that could have worked. But I had that experience in the late '90s: everybody is kumbaya when a startup starts and you say, “I will change the world.” When things get tough, or not even when things get tough but after a year or two of the kumbaya, investors will be asking, “Where is my return? Why aren’t you changing those people?” I knew that was not what I wanted.

I had never worked at or run a not-for-profit, but I was intrigued. In my day job I spent a lot of time talking to people and I saw how much capital structure motivates behavior and how your investor base motivates behavior. So I set up a not-for-profit. In a lot of ways this was a bolder bet because as risky as a for-profit venture-backed business is, the data indicate that a lot fewer not-for-profits make it to scale.

RML: In terms of your long-term vision for Khan Academy, you have been operating for close to a decade. Do you see any midcourse corrections? a long-term goal that would lead you to change the orientation? How do you see the whole enterprise going forward?

CAMERON FLETCHER (CHF): How will it be sustainable?

MR. KHAN: At a meta-level, with this whole notion of being a not-for-profit, our mission is a free, world-class education for anyone, anywhere. Every day that goes by I think, ‘Wow, that was a really good decision,’ and it keeps getting reinforced.

There is a Harvard Business School case study on Khan Academy, where the central question is, Should it be for-profit or not-for-profit? The main arguments against not-for-profit are: Will they have access to capital? Will they have access to talent, in order to tackle this huge, free, world-class education for anyone anywhere? I wasn’t even sure about it when it started.

But now the simple answer for both of those questions seems to be ‘yes.’ Not only are we getting decent talent, we are getting the best talent in Silicon Valley. Engineers and designers are hot commodities in Silicon Valley: everyone we give a job offer to has offers from Google, Facebook, Apple—and we are getting 70 percent of them. We have a higher yield than any of those other companies.

We pay well—our cash compensation is close to what people might be able to get from some of these other companies—but we don’t give stock. So the total compensation is maybe 50–60 percent of what you would get at some of these competitors. But it shows that if you pay people enough and give them a cool mission and intellectually challenging work, they feel like they are not a cog, like their work matters.

Some of the top people in the field are on our team and some of them are not driven by money at all. Craig Silverstein was Google’s first engineer; now he runs our infrastructure. He obviously could do anything with his time, but he wants to do this. We have people out of college, too, who could do anything and they are coming here.

The other thing is access to capital. I quit my job on the premise of the social return on investment here. I thought, ‘If I were a billionaire I would give to this.’ That may be a somewhat naïve point of view, and it took a little time, but now our funders are disproportionately engineers. They are people who care about education. They understand the scale we have and the types of measurement and tooling that we are capable of. They appreciate our analytics and how we try to measure and quantify what we do.

RML: In terms of sustainability, when you think about a university, for example, endowment is a very important part of the mix of financial resources at places like MIT and Harvard and other institutions. Are your donors contributing in the sense of operating funds or do you put some fraction of the resources into endowment? How do you envision sustaining the effort in the longer term?

Our mission is a free, world-class education for anyone, anywhere.

MR. KHAN: Right now our revenue makeup is about 40 percent of our budget, which in 2017 is $30–$35 million. About 40 percent of that will come from some of the folks I just talked about. The Gates Foundation and other large foundations are giving $1–3 million a year.

Another 40 percent of our revenue is from what we call “partner revenue.” It is not pure philanthropy because the partner is getting something out of it. For example, Bank of America sponsored financial literacy, and they get to tell the world, “We are sponsoring financial literacy on Khan Academy”—it’s part of their marketing that they care about education. The College Board gives us revenue to provide free practice for the SAT, which supports what they are doing and is great for us because it super aligns with our mission. We are talking to other testing companies.

We are finding that we can have a revenue model that in no way violates our mission. For example, SAT practice is free for students—it is a key part of their education—but it’s in another party’s interest to make it happen, so that party gives us support.

Another 20–25 percent of our revenue comes from small user donations. We have 300,000 people who give us on average $20. Hopefully we will always be able to make the case to large foundations that this is a very high social ROI and they will always be part of the mix. But I think the small donors may be a more predictable stream and we can do a lot more there. Right now it’s about $6–7 million a year; I think it could be $10, $15, $20 million a year if we make a little more effort. As our impact scales, I think that will happen.

We are working with more folks like the College Board, doing corporate sponsorship of content. We are
a completely noncommercial site—you won’t see any ads. But Amgen, as a real example, cares about biology education and would like to be associated with educating the next generation of biologists and researchers; they give us several million dollars as our biology sponsor. Similar to Bank of America.

But there is a very clear line. None of these donors have any editorial impact. It’s like the Olympics: “We are a proud sponsor of algebra and Khan Academy,” but it is noncommercial.

RML: I get it. You mentioned involvement with MIT. Does that involve their OpenCourseWare activities? What sort of interaction do you have with people there?

MR. KHAN: I don’t have any formal interaction with MIT, but obviously I interact a lot with it. I just saw [MIT president] Rafael Reif a couple of weeks ago at a conference. We always have fun conversations.

RML: Do you have any interaction with folks in the Media Lab?

MR. KHAN: I know a bunch of folks at the Media Lab, but we don’t have any formal partnerships with them. I do always cite OpenCourseWare as something of an inspiration for me. It reinforced my desire to make Khan Academy not-for-profit.

I remember in the late ’90s there were a bunch of for-profit startups partnering with colleges, and colleges were themselves saying, “Hey, this is a revenue stream. Let’s make some money off this.” Then I remember seeing the press release that MIT was giving it all away for free. They were putting money into it on principle. I found that to be incredibly inspiring. I felt very proud to come from MIT.

A lot of colleges talk about teaching ethics, but to take such a bold stance at the time, that is probably the best ethics of all. I gave a commencement address at MIT in 2012, and said this was an inspiration for me and that people should be proud.

CHF: You may be interested to know that the fall 2016 issue of The Bridge was devoted to open educational resources, starting with MIT. And this interview will be published in the spring 2017 issue, which will be on ethics, so you have that to look forward to as well.

RML: Talk about connectivity.

CHF: Going back to the matter of scaling, I see that you started off in the sciences and math and you have expanded to the arts and humanities. How do you pick the subjects that you are going to expand into? And are you considering other topics in those or other areas?

MR. KHAN: Yes, we look at where there is the most need and most demand. We are pretty comprehensive now from kindergarten through the core of college math. In another month or two, we will be almost fully comprehensive in introductory chemistry, biology, and physics. We are going into world history, American history, civics and government. So we are definitely expanding.

For us the vision that I have articulated with our team is that in the next 10 years we should cover every K–14 core academic subject—all the reading, writing, math,

2 The fall 2016 issue of The Bridge, with the story of MIT’s launching of OpenCourseWare, is available at https://www.nae.edu/Publications/Bridge/162252.aspx.
social sciences, the sciences, from pre-K or elementary school all the way through the first two years of college.

CHF: That is an unbelievably expansive ambit. I am wondering what are the pedagogical guidelines? How do you ensure that the team members you bring in have the right expertise to design content for such a range of courses and grade levels?

MR. KHAN: That is a central question. For K–12 math, for example, the Common Core standards set up at least an architecture. We have four or five in-house folks on it, then we work with teachers and researchers, and start writing items and creating content. I still create a lot of the videos but for math it would be vetted by Bill McCallum’s group at Illustrative Mathematics. Bill McCallum was one of the two authors of the math Common Core standards. They didn’t do this for anyone else.

This is kind of a secret weapon of being not-for-profit. They were not willing to do this for McGraw-Hill or Pearson, but they vetted every item, every piece of our content, to ensure that it is consistent with the spirit of the Common Core. This is a big deal because you can give the Common Core standards to a teacher, but how it gets implemented, who knows. With us, they can validate the words used, the visualizations, to make sure they’re consistent.

As we got into higher-level math and calculus we developed that content in conjunction with the math department at Phillips Academy Andover, which is where the Advanced Placement (AP) test started. They are one of those places where 150 kids take the test and 149 get a 5 on it.

We developed content with those teachers and now we are working with the College Board to vet it and make sure it’s exactly what they have in mind. They really get excited because, before, they just created the test and created some standards, and now they can say, “Hey, this is a pretty good reference curriculum.” Teachers can point their students to it. If a student goes to a school that doesn’t have AP classes, they have an alternative now in Khan Academy.

As we go into world history, civics, and government, we are talking closely to folks like the College Board.

In terms of the people we hire, let’s say for chemistry: our chemistry fellow is a PhD in chemistry from MIT and has taught all of the core chemistry classes. In addition, we usually ask them to create writing and even video samples, to see their take.

It is one thing to cover the standards—textbooks have been doing that forever, but they have also been really dry and hard to digest and they are not clear. So you can cover the standards, and even be pedagogically correct, but I would say the harder dimension is to really connect with people. Do they really feel comfortable with the material? And does it connect the conceptual dots? That’s the harder thing that we are getting better and better at looking for.

CHF: Especially when you branch out beyond the College Board or the SAT to the lower grades. If you’re talking about math or art or history for pre-K and first grade, for example, it seems to me that those would have different pedagogical needs. Do you have external reviewers?

MR. KHAN: Yes. And for the early learning stuff another exciting thing has happened recently. There is an app company called Duck Duck Moose—I have always cited it as best in class. It was started by a husband and wife who did it for their kids, so it is kind of a parallel narrative to what I was doing. They reached out to us a year ago and said they wanted to become a part of Khan Academy and were willing to donate their organization. They became part of Khan Academy and all 23 existing apps are now free. You can download them right now and start using them. Duck Duck Moose has experts on early learning, but they are also working with the education school at Stanford and other places.

RML: How many folks do you actually have? I was going to say subscribers. That may not be the right word. How many people do you reach a year?

MR. KHAN: There are different numbers. Some of these you could put in the category of vanity metrics, but more than 50 million registered users total, and 10 million people take a learning action per month—i.e., they did at least one thing.

CHF: Does that mean they completed a unit?
MR. KHAN: Yes, a unit for us could be as little as a video.

CHF: I was wondering because I went on your site and it says there are about 50 million learners. How are those measured? Is it the fact that I, for example, signed in so you guys now have my email address—does that make me one of the 50 million?

MR. KHAN: Yes, I think that’s the 50 million number you are seeing. That grows by 2–3 million people per month. If you look at unique users over a year, that number approaches 100 million. And the monthly number of people who take a learning action is 10–11 million right now.

RML: Do you know anything about the demographics of this population? How many of these are people who are beyond the K–12 system? The intention is that anyone who wants to learn something would have access.

MR. KHAN: Yes, I think that’s the 50 million number you are seeing. That grows by 2–3 million people per month. If you look at unique users over a year, that number approaches 100 million. And the monthly number of people who take a learning action is 10–11 million right now.

RML: Do you know anything about the demographics of this population? How many of these are people who are beyond the K–12 system? The intention is that anyone who wants to learn something would have access.

MR. KHAN: We are trying to get better data. The bulk of our users are in the middle school through early college age range. We do have a lot of adult learners. It’s hard to get precise information because a lot of our users are not registered and for the registered ones we don’t ask a lot about them. I would estimate probably 30 percent are out of school and doing it out of interest or trying to brush up to help their kids. And about 35 percent of our usage is outside the United States.

CHF: You do have an impressive array of languages into which your materials are translated.

MR. KHAN: Yes, that is exciting, and it’s growing. We have a full offering in five languages—the software is fully translated into Spanish, Brazilian Portuguese, Hindi, French, Turkish—and there are 20-some, maybe even 30 languages where we have a reasonable translation effort under way, done by volunteers. There are at least several hundred videos translated. I think there are 10,000 videos total in the entire library right now.

The other dimension of the vision is every core academic subject from kindergarten through core of college and in every major world language.

RML: That is stunning.

CHF: When you say that 30 percent of your users are older—defined as anybody beyond college—how much of your resources are used for continuing education and do you make any effort to reach out and do some promotion for that use?

MR. KHAN: Our number one testimonial comes from the continuing education person, the person who wants to go back to school and feels intimidated, especially by math. But we have to do a much better job about communicating it, tying it more closely to opportunities.

CHF: What do you see as next steps for yourself?

MR. KHAN: We have got our work cut out for us. We want to make the platform much more engaging. We see opportunities. We already have tools for teachers; how can we help them even more to free up time for more
interactive things with their students? More one-on-one time, more projects, dialogue, things like that.

We hope to tie learning on Khan Academy to actual opportunities. This is already true for some things like the SAT. But maybe you’re an adult learner and you prove yourself on Khan Academy and can take the actuarial exam now. If you do that you can have a pretty good career. Based on this work, we think we can give you a nurse apprenticeship or something like that.

That is not going to be us by ourselves. We are never going to be an assessment body or do job placement, but we can work with the people who do to create clear connections between learning on Khan Academy and some type of opportunity.

RML: Yours is quite a remarkable venture and a laudable effort. I am particularly impressed by your view of engaging people and educating them on a worldwide scale. That is important not only in terms of careers and personal well-being but also in terms of bringing people together around an educational goal that may help support world harmony.

MR. KHAN: I appreciate that and I agree with you.

RML: Before we close, is there any message you want to convey to the NAE members and other subscribers to The Bridge, who include members of Congress and deans of engineering throughout the country?

MR. KHAN: I think there is a lot of pessimism about what is going on in education. In the United States there is concern about a globalized world with automation—a world with a lot of productivity, but who is participating in that productivity?

As we transitioned from an industrial model, which is a bit of a pyramid, we had a lot of labor at the bottom and in the middle class, in information-processing jobs. A lot of labor in the industrial society was pretty good middle-class jobs, factory jobs, and the like. At the top were the owners of capital, the creative class, the researchers, artists, people like that.

Now the writing is on the wall. First through globalization, and shortly thereafter through automation: not only the bottom layer, through robotics, but even the middle layer, around information processing, is going to be automated. We are going to be a more productive society, but where does all that wealth go? Does it go to just the small top of the pyramid? Do we have an unstable society? Do we have to do some type of aggressive redistribution to have a stable society?

My hope, and I actually think it is possible, is that we invert that pyramid where instead of 5 or 10 percent of people at the top of the pyramid, maybe we can get 40, 50, even 60 percent of the population there. I call that the “Star Trek Reality,” where pretty much everyone is a researcher, an explorer, an entrepreneur, an artist of some kind.

CHF: What a beautiful optimistic view.

RML: Yes, it is. I hope that view becomes reality at some point. It would certainly be an asset to the whole planet.

MR. KHAN: We have 400 years to make Star Trek come true. I am working on it.
In February the NAE elected 84 new members and 22 foreign members, bringing the total US membership to 2,281 and the number of foreign members to 249.

Academy membership honors those who have made outstanding contributions to “engineering research, practice, or education, including, where appropriate, significant contributions to the engineering literature,” and to “the pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education.”

A list of the newly elected members and foreign members follows, with their primary affiliations at the time of election and a brief statement of their principal engineering accomplishments.

**New Members**

**David T. Allen,** Melvin H. Gertz Regents Chair in Chemical Engineering, McKetta Department of Chemical Engineering, University of Texas, Austin. For contributions to improving air quality and for developments in sustainable engineering education and practice.

**Ellen M. Arruda,** professor, macromolecular science and engineering, Department of Mechanical Engineering, University of Michigan, Ann Arbor. For pioneering research in polymer and tissue mechanics and their application in innovative commercial products.

**Aziz I. Asphahani,** chief executive officer, QuesTek Innovations LLC, Evanston, IL. For executive leadership in STEM education, integrated computer design of materials, and invention and production of corrosion-resistant alloys.

**David Vernon Boger,** professor, Department of Chemical Engineering, Monash University, Clayton, Victoria, Australia. For discoveries and fundamental research on elastic and particulate fluids and their application to waste minimization in the minerals industry.

**Arindam Bose,** consultant in business organization, biotechnology, bioengineering, and biosimilars, AbiologicsB LLC, Pawcatuck, CT. For innovations in the manufacture of biologics and service to the professional society organizations that represent the biopharmaceutical industry.

**Bimal K. Bose,** consultant and emeritus professor, Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville. For contributions to advancing power electronics technology and power conversion and education.

**Thomas P. Bostick,** senior vice president, environment sector, Intrexon Corp., Germantown, MD. For development of new approaches to hurricane protection and for leadership of the US Army Corps of Engineers.

**Ross W. Boulanger,** professor and director, Center for Geotechnical Engineering, Department of Civil and Environmental Engineering, University of California, Davis. For contributions to geotechnical earthquake engineering and the development of procedures for evaluating seismic behavior of soil-structure systems.

**Robert J. Budnitz,** staff scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory, University of California, Berkeley. For advancement of seismic probabilistic risk assessments and their application to nuclear power facilities.

**Cleopatra Cabuz,** vice president of engineering, Honeywell Industrial Safety, Honeywell Corp., Golden Valley, MN. For contributions to sensors, microelectromechanical technologies, and development of industrial and safety products.

**Gerbrand Ceder,** Chancellor’s Professor of Materials Science and Engineering, University of California, Berkeley. For the development of practical computational materials design and its application to the improvement of energy storage technology.

**Xiangli Chen,** vice president, General Electric Co., and president, GE China Technology Center, Shanghai. For pioneering work in optical sensing and precision laser processing, and for leadership in globalizing industrial research and development.

**Dianne Chong,** retired vice president, assembly, factory, and support technologies, Boeing Engineering, Operations, and Technology, Boeing Co., Bellevue, WA. For advances in process and production
technologies for composites in large commercial aerospace vehicles.

Joe H. Chow, professor, electrical and computer systems engineering, Rensselaer Polytechnic Institute, Troy, NY. For technical contributions to the modeling, analysis, and control of large-scale power systems.

Jingsheng Jason Cong, Chancellor’s Professor and director, Center for Domain-Specific Computing, Computer Science Department, University of California, Los Angeles. For pioneering contributions to application-specific programmable logic via innovations in field-programmable gate array synthesis.

James H. Crocker, vice president, international, and general manager, Lockheed Martin Space Systems Co., Littleton, CO. For technical leadership and engineering contributions in astrophysics and planetary exploration.

Mark David Dankberg, chair and chief executive officer, ViaSat Inc., Carlsbad, CA. For contributions to broadband Internet communications via satellite.

Mark S. Daskin, Clyde W. Johnson Collegiate Professor and chair, Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor. For leadership and creative contributions to location optimization and its application to industrial, service, and medical systems.

Whitfield Diffie, advisor, Black Ridge Technology, Redwood City, CA. For the invention of public key cryptography and for broader contributions to privacy.

Birol Dindoruk, principal technical expert of reservoir engineering, Shell Technology Center, Shell International E&P Inc., Houston. For significant theoretical and practical contributions to enhanced oil recovery and CO₂ sequestration.

Ali H. Dogru, chief technologist and fellow, computational modeling technology, EXPEC ARC (Exploitation and Petroleum Engineering Center–Advanced Research Center), Saudi Aramco/Saudi Arabian Oil Co., Dhahran, Saudi Arabia. For the development of high-performance computing in hydrocarbon reservoir simulation.

Eric H. DuCharme, general manager, advanced technology, GE Aviation, Cincinnati. For advancing the state of the art in composite fan technology and developing industry-leading aircraft engine technologies.

Dara Entekhabi, Bacardi and Stockholm Water Foundations Professor, Department of Civil and Environmental Engineering and Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge. For leadership in the hydrologic sciences including the scientific underpinnings for satellite observation of the Earth’s water cycle.

Rodney C. Ewing, Frank Stanton Professor in Nuclear Security, Center for International Security and Cooperation, and professor, Department of Geological and Planetary Sciences, Stanford University, CA. For studies on the long-term behavior of complex ceramic materials to assess their suitability for engineered nuclear waste sequestration.

Tillman U. Gerngross, co-founder and chief executive officer, Adimab LLC, Lebanon, NH. For founding and leading two successful biotechnology companies in the discovery and manufacture of biopharmaceuticals.

Jay Giri, director, power systems technology and strategic initiatives, GE Grid Solutions, General Electric Co., Redmond, WA. For contributions to utility control center technologies to enhance grid situational awareness and reliability.

Andrea Jo Goldsmith, Stephen Harris Professor of Engineering, Department of Electrical Engineering, Stanford University, CA. For contributions to adaptive and multi-antenna wireless communications.

George T. (Rusty) Gray III, laboratory fellow, Los Alamos National Laboratory, NM. For contributions to the understanding of the dynamic and shock-loading deformation and damage response of materials.

Leonidas J. Guibas, Paul Pigott Professor of Computer Science and Electrical Engineering, Computer Science Department, Stanford University, CA. For contributions to data structures, algorithm analysis, and computational geometry.

Selda Gunsel, general manager, products and quality, Shell Global Lubricants Supply Chain, Royal Dutch Shell PLC, Houston. For leadership in developing and manufacturing advanced fuels and lubricants to meet growing global energy demand while reducing CO₂ emissions.

Paula Therese Hammond, Ida Green Education Professor, chief executive officer, and director, Singapore-MIT Alliance for Research and Technology, Massachusetts Institute of Technology, Singapore. For contributions to the development of biotechnology and for broader contributions to privacy.

Daniel E. Hastings, Cecil and Ida Green Education Professor, chief executive officer, and director, Singapore-MIT Alliance for Research and Technology, Massachusetts Institute of Technology, Singapore. For contributions to the development of biotechnology and for broader contributions to privacy.
Institute of Technology, Cambridge. For contributions in spacecraft and space system–environment interactions, space system architecture, and leadership in aerospace research and education.

Julia Hirschberg, Percy K. and Vida L.W. Hudson Professor of Computer Science, and chair, Department of Computer Science, Columbia University, New York City. For contributions to the use of prosody in text-to-speech and spoken dialogue systems, and to audio browsing and retrieval.

William T. Holmes, senior consultant, Rutherford & Chekene, Consulting Structural Engineers, San Francisco. For excellence in structural design and leadership in improving the seismic safety of buildings.

Jennifer R. Holmgren, chief executive officer, LanzaTech, Skokie, IL. For developing technologies to improve our energy future, from renewable energy and chemicals to combinatorial chemistry and materials discovery.

Kathleen Connor Howell, associate dean for engineering and Hsu Lo Distinguished Professor of Aeronautics and Astronautics, Purdue University, West Lafayette, IN. For contributions in dynamical systems theory and invariant manifolds culminating in optimal interplanetary trajectories and the Interplanetary Superhighway.

Yonggang Huang, Walter P. Murphy Professor of Engineering, Department of Mechanical Engineering, Northwestern University, Evanston, IL. For pioneering work on mechanics of stretchable electronics and mechanically guided, deterministic 3-D assembly.

Mir A. Imran, chair and chief executive officer, Incube Ventures, San Jose, CA. For his role in creating the first implantable cardiac defibrillator, and for developing multiple other technologies as inventor and entrepreneur.

Dina Katabi, professor, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge. For contributions to network congestion control and to wireless communications.

Dimitris E. Katsoulis, senior research scientist, Dow Corning Corp., Midland, MI. For foundational contributions to the characterization and creation of novel silicone resins, gels, and elastomers, and catalysis for organosilanes.

Yann A. LeCun, director, AI Research, Facebook, New York City. For developing convolutional neural networks and their applications in computer vision and other areas of artificial intelligence.

L. Ruby Leung, laboratory fellow, Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, US Department of Energy, Richland, WA. For leadership in regional and global computer modeling of the Earth’s climate and hydrological processes.

Jennifer A. Lewis, Hansjorg Wyss Professor of Biologically Inspired Engineering, Harvard University, Cambridge, MA. For development of materials and processes for 3-dimensional direct fabrication of multifunctional structures.

George T. Ligler, consultant, GTL Associates, Fuquay-Varina, NC. For leadership and engineering innovation in specifying and implementing complex computer-based systems for aviation and the US Census.

Steven B. Lipner, executive director, SAFECode, Wakefield, MA. For developing and deploying practical methods for engineering secure software and computer systems.

Tsu-Jae K. Liu, TSMC Distinguished Professor in Microelectronics and chair, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley. For contributions to the FinFET transistor (FinFET) and its application to nanometer complementary metal-oxide-semiconductor (CMOS) technology.

Robert W. McCabe, program director, Division of Chemical, Bioengineering, Environmental, and Transport Systems, National Science Foundation, Arlington, VA. For enabling ultraclean vehicles through conceptual and practical advances in catalytic systems for the abatement of automotive emissions.

Piotr D. Mochnarz, principal engineer, buildings and structures, Exponent, Menlo Park, CA. For dedication to global improvement of the safety and reliability of engineering systems and to cooperation beyond political borders.

John R. Monnier, research professor, chemical engineering, University of South Carolina, Columbia. For the discovery and development of the silver-catalyzed epoxidation of non-allylic olefins to produce 3,4-epoxy-1-butene and other non-allylic olefin epoxides.

Omkaram Nalamasu, senior vice president and chief technology officer, Applied Materials Inc., and president, Applied Ventures LLC, Santa Clara, CA. For technical innovation spanning materials development, atomically controlled thin film fabrication, and commercialization in microelectronics and energy generation and storage.

Jagdish Narayan, John C.C. Fan Distinguished Chair Professor,
Department of Materials Science and Engineering, North Carolina State University, Raleigh. For contributions in heteroepitaxial film growth by laser ablation in large misfit systems and new materials.

Arkadi Nemirovski, John Hunter Chair and professor, H. Milton Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta. For the development of efficient algorithms for large-scale convex optimization problems.

Debbie A. Niemeier, professor, Department of Civil and Environmental Engineering, University of California, Davis. For developing groundbreaking tools to characterize the impact of transportation emissions on air quality and environmental justice.

Marc Brendan Parlange, dean, Faculty of Applied Science, and professor, Department of Civil Engineering, University of British Columbia, Vancouver, Canada. For fundamental contributions to land-atmosphere modeling and leadership in field measurement campaigns over complex terrain.

Randall W. Poston, senior principal, Pivot Engineers, Austin, TX. For development of diagnostic and repair technologies for concrete structures and leadership in concrete building code development.

Behzad Razavi, professor, Department of Electrical Engineering, University of California, Los Angeles. For contributions to low-power broadband communication circuits.

Jon C. Schaeffer, senior engineering manager, materials and processes engineering, GE Power & Water, Greenville, SC. For contributions to the development and implementation of advanced materials in industrial gas turbine engines.

Daniel Jay Scheeres, Distinguished Professor and A. Richard Seebass Endowed Chair Professor in Aerospace Engineering Sciences, University of Colorado Boulder. For pioneering work on the motion of bodies in strongly perturbed environments such as near asteroids and comets.

Darrell G. Schlom, Herbert Fisk Johnson Professor of Industrial Chemistry, Department of Materials Science and Engineering, Cornell University, Ithaca, NY. For molecular-beam epitaxy “Materials-by-Design” of complex oxides impacting the integration of high dielectric oxides in semiconductor devices.

Dominick M. Servedio, executive chair, STV Group, New York City. For leadership and effective advocacy on behalf of the engineering and construction professions.

E. Sarah Slaughter, chief executive officer and founder, Built Environment Coalition, Cambridge, MA. For research and the development of technology to enhance the resiliency and sustainability of critical infrastructure systems.

Alexander H. Slocum Jr., professor, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge. For contributions to precision machine design and manufacturing across multiple industries and leadership in engineering education.

Megan Joan Smith, former US Chief Technology Officer and assistant to the president, White House Office of Science and Technology, Washington, DC. For leading technological innovation teams and efforts to increase diversity and inclusion in STEM industries both nationally and globally.

Darlene Joy Spira Solomon, senior vice president and chief technology officer, Agilent Technologies, Santa Clara, CA. For leadership in the development of innovative nucleic acid and microfluidic products for the life science and molecular diagnostic industries.

Philippe R. Spalart, senior technical fellow, Boeing Commercial Airplanes, Seattle. For development and application of a broad array of computational techniques for the prediction of aerodynamic turbulence and noise.

Michael R. Splinter, general partner, WISC Partners, Los Altos, CA. For business leadership advancing semiconductor manufacturing, quality, and equipment.

Michael S. Strano, Carbon P. Dubbs Professor of Chemical Engineering, Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge. For contributions to nanotechnology, including fluorescent sensors for human health and solar and thermal energy devices.

Sridhar R. Tayur, Ford Distinguished Research Chair Professor of Operations Management, Tepper School of Business, Carnegie Mellon University, Pittsburgh. For developing and commercializing innovative methods to optimize supply chain systems.

Mehmet Toner, Helen Andrus Benedict Professor, Surgery, Massachusetts General Hospital, and professor of health sciences, Harvard-MIT Division of Health Sciences and Technology, Boston. For engineering novel microelectromechanical and microfluidic
point-of-care devices that improve detection of cancer, prenatal genetic defects, and infectious disease.

Paul J. Turinsky, professor, Department of Nuclear Engineering, North Carolina State University, Raleigh. For the development of simulation technology for the economic operation, safety, and life extension of nuclear power stations.

Reinaldo A. Valenzuela, director, wireless communications research, Nokia Bell Labs, Holmdel, NJ. For leadership in development of multi-antenna wireless communication systems and channel modeling.

Gordon van Welie, president and chief executive officer, ISO New England, Holyoke, MA. For improving reliable operation of the power grid through enhanced grid control, new market structures, and innovative transmission planning.

David M. Van Wie, mission area executive, precision strike mission area, Applied Physics Laboratory, Johns Hopkins University, Laurel, MD. For contributions to hypersonic technology enabling new classes of flight vehicles.

George Varghese, Chancellor’s Professor, Department of Computer Science, University of California, Los Angeles. For network algorithms that make the Internet faster, more secure, and more reliable.

Suzanne M. Vautrinot, president, Kilovolt Consulting Inc., San Antonio. For leading the creation of a revolutionary organization designed to provide the nation an enhanced cyber capability.

Barry Voight, professor emeritus of geology and geological engineering, Pennsylvania State University, University Park. For contributions to the understanding, management, and mitigation of geologic hazards.

Charles K. Westbrook, retired senior scientist, Lawrence Livermore National Laboratory, Livermore, CA. For pioneering development, applications, and leadership in chemical kinetic modeling to advance combustion science and technology.

Blake S. Wilson, codirector, Duke Hearing Center, Duke University Medical Center, Durham, NC. For engineering development of the cochlear implant that bestows hearing to individuals with profound deafness.

Peter J. Winzer, director, Optical Transmission Systems and Network Research, Nokia Bell Labs, Holmdel, NJ. For contributions to high-speed, coherent optical communication systems.

Ioannis V. Yannas, professor of polymer science and engineering, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge. For codeveloping the first commercially reproducible artificial skin that facilitates new growth, saving the lives of thousands of burn victims.

Martin L. Yarmush, Paul and Mary Monroe Chair Distinguished Professor, biomedical engineering, Rutgers University, Piscataway, NJ. For pioneering advances in cellular, tissue, and organ engineering and for leadership in applying metabolic engineering to human health.

Katherine A. Yelick, associate laboratory director, computer science, Lawrence Berkeley National Laboratory, and professor, electrical engineering and computer science, University of California, Berkeley. For software innovation and leadership in high-performance computing.

Dongxiao (Don) Zhang, dean of engineering and chair professor, water resources and petroleum engineering, Peking University, Beijing. For pioneering work in stochastic modeling of flow in porous media.

New Foreign Members

Sergio Manuel Alcocer, research professor, Institute of Engineering, National Autonomous University of Mexico, Mexico City. For improvements to the seismic safety of buildings in developing countries through improved design standards and government policies.

Yasuhiro Arakawa, professor, Electrical Engineering Department, University of Tokyo. For contributions to quantum dot lasers and related nanophotonic devices.

Chieko Asakawa, chief technology officer for accessibility research and technology, IBM Research Tokyo, IBM Japan Ltd., Tokyo. For developing technologies for the visually impaired to access digital information.

Keith John Beven, Distinguished Professor of Hydrology, Lancaster Environmental Centre, Lancaster University, United Kingdom. For contributions to the understanding of hydrological processes and development of the foundations of modern hydrological modeling.

Bernard Charlès, president and chief executive officer, Dassault Systèmes, Vélizy-Villacoublay, France. For leadership in providing major software tools for simulation-based engineering.

F. Stuart Foster, professor and Canada Research Chair in Ultrasound Imaging, Department of Medical Biophysics, University of Toronto. For pioneering the field of high-frequency ultrasound and translating its technologies into clinical and preclinical imaging systems.

Michimasa Fujino, president and chief executive officer, Honda
Aircraft Co., Greensboro, NC. For the creation of the HondaJet and formation of the Honda Aircraft Company.

Martin Fussenegger, professor, biotechnology and bioengineering, Department of Biosystems Science and Engineering, ETH Zürich, Basel, Switzerland. For contributions to synthetic biology and engineered therapeutic gene networks.

Georges Hadziioannou, University Professor Classe Exceptionnelle, Laboratoire de Chimie des Polymères Organiques, Université de Bordeaux, Pessac, France. For foundational discoveries and insights enabling the development of polymers with advanced functionality and performance.

Horst Hahn, director, Institute of Nanotechnology, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany. For contributions to the science and engineering of nanostructured materials with tailored and tunable properties.

Kazunori Kataoka, professor, biomaterials, Department of Bioengineering, University of Tokyo. For pioneering contributions to the design of supramolecular nanostructures and their application to drug and gene delivery systems.

Noboru Kikuchi, president and chief operating officer, Toyota Central R&D Labs Inc., Aichi, Japan. For contributions to theory and methods of computer-aided engineering and leadership in their applications in the automotive industry worldwide.

Reiner Kirchheim, distinguished professor of the state of Lower Saxony, University of Göttingen, Germany. For contributions to the thermodynamics and kinetics of hydrogen behavior in metals and solute/defect interactions in other materials.

Johannes A. Lercher, chair, technical chemistry, Department of Chemistry, Technical University, Munich. For developing concepts and catalysts for activating and functionalizing hydrocarbons and for upgrading fossil and biogenic feedstocks via heteroatom removal.

Detlef Lohse, chair, Department of Physics of Fluids, University of Twente, Enschede, Netherlands. For contributions to fundamental fluid mechanical processes, especially turbulence in Rayleigh-Bénard and Taylor-Couette flow, sonoluminescence drops, and surface nanobubbles.

Stéphane Mallat, professor, computer science, École Normale Supérieure, Paris. For contributions to the fast wavelet transform and multiresolution signal processing.

Cyril Thomas O’Connor, professor emeritus and senior research scholar, Department of Chemical Engineering, University of Cape Town, Rondebosch, South Africa. For contributions to the sustainable recovery of minerals from complex ores and for the global advancement of mineral processing technology.

Heung-Yeung Shum, executive vice president, technology and research, Microsoft Corp., Redmond, WA. For contributions to computer vision and computer graphics, and for leadership in industrial research and product development.

Joseph Sifakis, professor, School of Computer and Communication Science, École Polytechnique Fédérale de Lausanne, Switzerland. For coinventing model checking and for contributions to the development and verification of real-time and embedded systems.

Colin P. Smith, group president, Rolls-Royce PLC, Derbyshire, United Kingdom. For leadership in design, technologies, and manufacturing processes that enhance airworthiness, safety, and environmental sustainability of large aeroengines.

Constantinos G. Vayenas, professor, Department of Chemical Engineering, University of Patras, Greece. For fundamental studies on electrochemical modification of catalytic activity leading to the industrial design and use of new promoted catalysts.

Dennis A. Woodford, president, Electranix Corp., Winnipeg, Manitoba, Canada. For developing analytical methods related to HVDC transmission and high-power DC-DC transformation systems.
The Presidential Medal of Freedom is the nation’s highest civilian honor, presented to individuals who have made especially meritorious contributions to the security or national interests of the United States, to world peace, or to cultural or other significant public or private endeavors.

At a lighthearted White House ceremony on November 22, President Barack Obama presented the Presidential Medal of Freedom. In his opening remarks, he said, “The Presidential Medal of Freedom is not just our nation’s highest civilian honor—it’s a tribute to the idea that all of us, no matter where we come from, have the opportunity to change this country for the better. From scientists, philanthropists, and public servants to activists, athletes, and artists, these 21 individuals have helped push America forward, inspiring millions of people around the world along the way.” Among the 21 people honored were three NAE members.

Richard Garwin, IBM Fellow Emeritus, IBM Thomas J. Watson Research Center, received the honor in recognition of a long career of research, invention, and advice to policymakers. He is a polymath physicist who earned a PhD under Enrico Fermi at age 21 and went on to make pioneering contributions to US defense and intelligence technologies, low-temperature and nuclear physics, detection of gravitational radiation, magnetic resonance imaging (MRI), computer systems, laser printing, and nuclear arms control and nonproliferation. He directed applied research at IBM’s Thomas J. Watson Research Center and taught at the University of Chicago, Columbia University, and Harvard University. The author of 500 technical papers and a winner of the National Medal of Science, he holds 47 US patents and has advised numerous administrations.

Bill and Melinda Gates were recognized for their humanitarian work. The Bill & Melinda Gates Foundation was established in 2000 “to help all people lead healthy, productive lives.” In developing countries, the foundation focuses on improving people’s health and giving them the chance to lift themselves out of hunger and extreme poverty. In the United States, the mission is to ensure that all people—especially those with the fewest resources—have access to the opportunities they need to succeed in school and life.
The Gates Foundation has provided more than $36 billion in grants since its inception.

Grace M. Hopper (1906–1992), senior consultant, Digital Equipment Corporation, and retired Rear Admiral, US Navy Reserve, received the medal posthumously. Her citation reads “As a child who loved disassembling alarm clocks Rear Adm. Grace Murray Hopper found her calling early. Known today as the ‘queen of code’ Grace Hopper’s work helped make the coding language more practical and accessible. . . . Amazing Grace was committed to making the language of computer programming more universal. Today we honor her contributions to computer science and the sense of possibility she inspired for generations of young people.”

NAE Newsmakers

Norman R. Augustine, retired chair and CEO, Lockheed Martin Corporation, has received the inaugural Gold Key Award, Sigma Xi’s highest accolade. The award is presented to a member who has made extraordinary contributions to his or her profession and has fostered critical innovations to enhance the health of the research enterprise, to cultivate integrity in research, or to promote the public understanding of science for the purpose of improving the human condition.

On November 1, 2016, B. Jayant Baliga, Distinguished University Professor, North Carolina State University, was inducted as a foreign fellow of the Indian National Academy of Engineering (INAE) for outstanding accomplishments in power semiconductor device technology. The INAE elects only five foreign fellows each year. It is one of the highest professional distinctions accorded to an engineer in India.

Simon R. Cherry, Distinguished Professor, University of California, Davis, and Mohammad Shahidehpour, Bodine Chair Professor, Illinois Institute of Technology, have been elected 2016 Fellows of the American Association for the Advancement of Science.

The American Society of Civil Engineers has honored two NAE members with Outstanding Projects and Leaders (OPAL) Awards. Bruce R. Ellingwood, professor, Department of Civil and Environmental Engineering, Colorado State University, received the OPAL Award for Education for demonstrated excellence in furthering civil engineering education. Harry G. Poulos, senior consultant, Coffey Geotechnics, was presented the OPAL Award for Design for innovation and excellence in civil engineering design.

Herbert Gleiter, professor, Institute of Nanotechnology, Karlsruhe Institute of Technology, has received the Medal of Friendship–Order of Merit from the Government of China, Jiangsu Province. This order was awarded—for the first time to a citizen from abroad—for the successful foundation in 2011 of the Herbert Gleiter Institute of Nanoscience at Nanjing.

Asad M. Madni, independent consultant and retired president, COO, and CTO, BEI Technologies Inc., was presented the IEEE San Fernando Valley Section Visionary Leadership Award at its annual awards banquet on December 21, 2016. Dr. Madni received the award for “visionary leadership, remarkable innovations, and seminal and pioneering contributions to science and technology that have had a worldwide impact and significantly benefited humanity.”

Richard K. Miller, president and professor of mechanical engineering, Franklin W. Olin College of Engineering, is the 2017 Brock International Prize in Education Laureate for his many contributions to the reinvention of engineering education in the 21st century. The Brock Prize recognizes individuals who have made a specific innovation or contribution resulting in a significant impact on the practice or understanding of the field of education. The prize committee noted that, “Driven by Miller’s vision, Olin has become a model of project-based, design-centric education for engineering and non-engineering schools alike in the US and abroad.” Dr. Miller was formally honored on March 8 at the annual Brock Prize Symposium at the University of Oklahoma, where he was the featured speaker. As part of the award, he received $40,000 from the Brock Foundation and a bust of legendary Native American educator Sequoyah.

Judea Pearl, Chancellor’s Professor, University of California, Los Angeles, has been selected for the 2017 Sells Award for Distinguished Multivariate Research.
The award recognizes an individual who has made distinguished lifetime contributions to multivariate analysis in psychology. Professor Pearl will accept the award and deliver an address at the organization’s October 2017 meeting in Minneapolis.

Celestino R. Pennoni, chair of the board, Pennoni Associates Inc. Consulting Engineers, was selected to receive the 2016 William Penn Award, the highest honor bestowed on a business executive in Greater Philadelphia, on April 21. The award, given annually since 1949, recognizes an individual for outstanding contributions toward the betterment of the region, professional accomplishments, and commitment to charity as well as to the community.

Henry I. Smith, professor of electrical engineering emeritus, Massachusetts Institute of Technology, has been awarded the 2017 IEEE Robert N. Noyce Medal in recognition of his “contributions to lithography and nanopatterning through experimental advances in short-wavelength exposure systems and attenuated phase-shift masks.”

Richard A. Tapia, University Professor and Maxfield-Oshman Professor in Engineering, Rice University, received the American Association for the Advancement of Science’s 2016 AAAS Public Engagement with Science Award for his “remarkable career blending world-class scholarship, admirable mentoring, and profound contributions to science, technology, engineering, and mathematics education and public engagement.” The award was presented February 17 at the AAAS annual meeting in Boston.

On April 30 four NAE members will be recognized for their extraordinary achievements in the physical sciences and engineering by the National Academy of Sciences during its 154th annual meeting. Jerome H. Milgram, professor emeritus in the MIT Department of Mechanical Engineering, will receive the 2017 Gibbs Brothers Medal for “wideranging original contributions to naval architecture in theoretical hydromechanics, education, yacht design, environmental protection, and the practical arts of ocean systems.” Leroy E. Hood, president and cofounder, Institute for Systems Biology, will receive the 2017 NAS Award for Chemistry in Service to Society for “his invention, commercialization, and development of multiple chemical tools that address biological complexity, including the automated DNA sequencer that spearheaded the human genome project.” Robert H. Dennard, IBM Fellow Emeritus, IBM Thomas J. Watson Research Center, will receive the 2017 NAS Award for the Industrial Application of Science for “seminal contributions in the field of microelectronics for the invention of dynamic random access memory (DRAM) and CMOS scaling.” Frances H. Arnold, Dick and Barbara Dickinson Professor of Chemical Engineering, Bioengineering, and Biochemistry at the California Institute of Technology, will receive the 2017 Raymond and Beverly Sackler Prize in Convergence Research for “her pioneering directed molecular evolution strategies, used worldwide to optimize the functions of enzymes and to engineer cells to produce biofuels and chemicals from renewable resources.”

In a ceremony during the November 2016 annual meeting in San Francisco, the American Institute of Chemical Engineers (AIChE) presented awards to several NAE members. Its highest honor, the AIChE Founders Award for Outstanding Contributions to the Field of Chemical Engineering, was presented to Klavs F. Jensen, Warren K. Lewis Professor of Chemical Engineering and professor of materials science and engineering, Massachusetts Institute of Technology. Glenn H. Fredrickson, professor of chemical engineering and materials and CTO, Mitsubishi Chemical Holdings, University of California, Santa Barbara, received the William H. Walker Award for Excellence in Contributions to Chemical Engineering Literature. The Lawrence B. Evans Award in Chemical Engineering Practice was presented to Richard W. Korsmeyer, executive director, Advanced External Projects, Pfizer Worldwide R&D. And James A. Trainham, chief technology officer, JDC/Phosphate, received the Industry Leadership Award.

The National Academy of Inventors (NAI) chooses for induction as NAI Fellows individuals who “have demonstrated a highly prolific spirit of innovation in creating or facilitating outstanding inventions that have made a tangible impact on quality of life, economic development, and the welfare of society.” On April 6 the 2016 NAI Fellows will be inducted in a ceremony at the John F. Kennedy Presidential Library and Museum in Boston. NAE members being inducted are B. Jayant Baliga, Distinguished University Professor, North Carolina State University; Zhenan Bao, professor of chemical engineering, Stanford University; Barbara D. Boyan, dean, School of Engineering, Virginia Commonwealth University; Ruben G. Carbonell,
Frank Hawkins Kenan Distinguished Professor of Chemical and Biomolecular Engineering, North Carolina State University; Simon R. Cherry, professor, Department of Biomedical Engineering, University of California, Davis; Michael J. Cima, David H. Koch Professor of Engineering, MIT; Larry A. Coldren, Fred Kavli Professor of Optoelectronics and Sensors, UC Santa Barbara; Delbert E. Day, Curators’ Professor Emeritus of Materials Science and Engineering and senior investigator, Missouri University of Science and Technology; Stephen W. Director, University Distinguished Professor and provost emeritus, Northeastern University; Herbert Gleiter, professor, Institute of Nanotechnology, Karlsruhe Institute of Technology; Dan M. Goebel, senior research scientist, Advanced Propulsion Technology Group, Jet Propulsion Laboratory/Caltech; John B. Goodenough, Virginia H. Cockrell Centennial Chair in Engineering, University of Texas at Austin; Mark S. Huma-yun, Cornelius J. Pings Chair in Biomedical Sciences, University of Southern California; Enrique Iglesias, Theodore Vermeulen Chair in Chemical Engineering, UC Berkeley; Sungho Jin, professor emeritus, Department of Mechanical and Aerospace Engineering, UC San Diego; John L. Junkins, Distinguished Professor of Aerospace Engineering, Texas A&M University–College Station; John Klier, professor and head, Department of Chemical Engineering, University of Massachusetts Amherst; Enrique J. Lavernia, provost and executive vice chancellor, UC Irvine; Frances S. Ligler, Lampe Distinguished Professor of Biomedical Engineering, Joint Department of Biomedical Engineering, UNC Chapel Hill and NC State University; Yilu Liu, Governor’s Chair Professor, Electrical Engineering and Computer Science Department, University of Tennessee; Raghunath A. Mashelkar, National Research Professor, National Chemical Laboratory, India; Edward W. Merrill, CP Dubbs Professor of Chemical Engineering Emeritus, MIT; David J. Mooney, Robert P. Pinkas Family Professor of Bioengineering, Harvard University; Bruce E. Rittmann, Regents’ Professor of Environmental Engineering, Arizona State University; Ponisseril Somasundaran, director, NSF/IUCR Center for Surfactants and La Von Duddleson Krumb Professor, Columbia University; Anil V. Virkar, professor and chair, Department of Materials Science and Engineering, University of Utah; Andrew M. Weiner, Scifres Distinguished Professor, School of Electrical and Computer Engineering, Purdue University; Jennifer L. West, Fitzpatrick Family University Professor, Department of Biomedical Engineering, Duke University; and Amnon Yariv, Martin and Eileen Summerfield Professor of Applied Physics and professor of electrical engineering, California Institute of Technology.

A Message from NAE Vice President Corale L. Brierley

I am pleased to report on a very robust fundraising year for the NAE. Thanks to the generosity of 639 members and friends, we raised over $7.1 million in new cash and pledges in 2016 to support our efforts to promote a vibrant engineering profession and increase public awareness of the importance of engineering to our national prosperity. Both unrestricted and restricted contributions were well ahead of 2015 totals. Over $2.5 million was raised for unrestricted purposes, including $1.9 million to the NAE Independent Fund and $626,000 for the President’s Initiatives Fund. This would equate to a $42.9 million endowment equivalent, assuming a 4.5% draw that could be used as flexible funds. Unrestricted support not only provides core support but also allows us to initiate important new projects that lack federal funding and help expand the scope and impact of current programs.

We also received $4.5 million for projects (restricted), including support for the Global Grand Challenges Summit, the Grand Challenges Scholars Program (GCSP) Network and general Grand Challenges activities, LinkEngineering, the Center for Engineering Ethics and Society, EngineerGirl, this year’s E4U Video Contest,
Frontiers of Engineering (FOE), Frontiers of Engineering Education (FOEE), prizes, and other programs. Approximately 56% of the funding came from corporations and/or foundations. We had 100% giving participation from the NAE Council for a second year in a row—a sincere gesture of commitment by our leadership.

We are also happy to welcome quite a few new members to our giving societies. In 2016 the NAE added 9 new Einstein Society members (lifetime giving of $100,000+), 20 new Golden Bridge Society members (lifetime giving of $20,000–$100,000), and 3 new Heritage Society members and others making a second planned gift or increasing their estate commitments.

This extraordinary philanthropic support provides for 30% of the NAE’s annual budget, and we are grateful for our donors’ confidence in our ability to use their contributions to serve the engineering community, students, policymakers, and the public. As a nonprofit organization, the NAE receives no government appropriation for operations.

Both Chairman Gordon England and President Dan Mote have made philanthropy a priority of their terms of office. During his first annual meeting address Gordon England said, “my goal as chairman is to provide sustainable funding for the Academy as the means to continuously improve the engineering profession and the standing of the profession in the world. We are uniquely situated to foster the growing momentum of the Grand Challenges for Engineering program so we can tackle major issues and inspire students to pursue engineering.” He went on to announce the creation of a $100,000 Chairman’s Challenge for Section 1 that he is personally funding, and asked others to join him in creating matching gift challenges for each section by the 2017 annual meeting. Here are the results as of December 31, 2016:

**Section 1:** raised $106,000 in new gifts and pledges.

**Section 2:** The Fran and George Ligler Challenge for Section 2 continued to inspire Section 2 members to make new and increased gifts. Started in 2015, the goal is to raise $100,000 by 2019. Thirty Section 2 members made gifts in 2016 that qualified for the match, totaling over $45,000. Since the inception, $80,000 has been raised, and we are 80% to reaching the goal and on track to reach it 2 years early.

**Section 4:** $25,000 challenge funded by Paul Boulos.

**Section 5:** $100,000 challenge funded by Gordon Bell, Tom Leighton, and Bob Sproull.

**Section 7:** $100,000 challenge funded by James Truchard. As of end-2016, the challenge had raised $887,000.

The Sanjit K. Mitra Family Challenge for Newer Members was launched with a $100,000 gift to encourage members in the classes of 2013–2016 to support the NAE and our programs. Sanjit Mitra’s passion has been engineering education, and it was fitting that he directed his gift to support the Frontiers of Engineering Education program. The Mitra Challenge raised over $171,000 in new cash and $835,000 in new pledges from 76 donors.

### February Council Dinner and Financial, Tax, and Estate Planning Session

The NAE hosted its annual February Council Dinner in Newport Beach; the night before the national meeting. This dinner is an opportunity for members, donors, and friends in the area to interact with the NAE Council and meet, socialize, and hear about developments at the NAE. For the 4th time, the NAE also hosted a Financial, Tax, and Estate Planning seminar just before the dinner, led by Jamie Killorin, director of planned giving. This seminar has become popular during the annual meeting in Washington, and we want to offer members on the West Coast opportunities to learn more about making tax-wise estate plans and how best to incorporate their philanthropic priorities.

### Golden Bridge Society Dinner

During the 2016 NAE annual meeting President Mote and his wife Patsy hosted some of NAE’s most generous members and friends at the Golden Bridge Society Dinner, at the Smithsonian Castle on Sunday, October 9. We welcomed a dozen new donors into the Academy’s three lifetime recognition societies.

### Noteworthy Contributions

The NAE received some remarkable gifts in 2016. While all contributions are greatly appreciated and make a difference in the Academy’s work, the following gifts show extraordinary commitment to the NAE:

- **The Boeing Charitable Trust** generously gave $1 million in support of the Grand Challenges Scholars Program (GCSP) and the Global Grand Challenges Summit to be held July 18–20, 2017, in Washington, DC.
• Chevron Corporation committed $500,000 to sustain LinkEngineering, an online resource and community of educators interested in providing meaningful engineering experiences to preK–12 students of all abilities.

• The Charles Stark Draper Laboratory contributed over $237,000 to cover the operating costs and selection committee’s work for the Draper Prize for Engineering.

• Dotty and Gordon (’12) England committed $100,000 to fund the Chairman’s Challenge and to support the NAE Independent Fund, and notified us that they have included the NAE in their estate plans.

• ExxonMobil gave $100,000 to support the E4U video contest.

• General Electric Corporation contributed $100,000 to support Making Value for America.

• Ming (’15) and Eva Hsieh made a new $750,000 commitment to support the Global Grand Challenges Student Day Play-Offs and the NAE Independent Fund.

• Lockheed Martin committed $500,000 to support the Global Grand Challenges Summit.

• John F. McDonnell gave $125,000 in support of Frontiers of Engineering Education.

• Sanjit K. (’03) and Nandita Mitra gave $100,000 to support the Global Grand Challenges Summit.

• Northrop Grumman committed $1 million to sponsor the Global Grand Challenges Summit.

• The Shell Company gave $250,000 to the Global Grand Challenges Summit.

• James Truchard (’07) made a $100,000 gift to the Independent Fund in response to the Chairman’s Challenge to fund a challenge for Section 7.

• Andrew Viterbi (’78) directed his $500,000 Draper Prize cash award to the NAE—the first time in the Draper Prize’s almost 30-year history—to support the President’s Initiatives Fund for activities aimed at attracting bright young people to engineering education and careers.

If you are interested in making a gift to the NAE, please contact Radka Nebesky, NAE director of development, at 202.334.3417 or RNebesky@nae.edu.

Loyal Donors

Gifts made regularly each year to the NAE demonstrate genuine commitment to our mission and goals. As a long-time donor who understands that every donation to the NAE is a choice to support an organization whose work I believe matters greatly, I thank the Loyalty Society members (pages 90–91) who have contributed to the NAE for 20 years or more.

I am a big believer in explaining what your generosity has allowed the NAE to accomplish and the impact of your philanthropic investments. Below are two examples of what philanthropic support helped accomplish in 2016:

• With support from Boeing, Lockheed Martin, Northrop Grumman, Shell, and several individuals, the NAE began planning the 3rd Global Grand Challenges Summit (in Washington, DC, July 18–20, 2017) to extend and inspire international cooperation in addressing the most pressing issues of our time. The NAE Grand Challenges for Engineering have become an international movement inspiring young people and professionals alike to focus on major issues facing everyone around the world in this century, such as clean water and securing cyberspace, plus 12 others.

• With support from Boeing and several individuals, the NAE focused on the Grand Challenges Scholars Program (GCSP), a supplemental education model designed to engage and prepare students to undertake problems like the Grand Challenges. The program engages students in research and in interdisciplinary learning with clients and mentors; exposes them to viable business creation and innovation experiences; helps them gain global and cross-cultural perspectives; and encourages them to develop social consciousness through service learning. In addition to hiring the first director of the program, 2016 saw the first annual meeting of the GCSPs in conjunction with the White House Office of Science and Technology Policy, to discuss best practices, increasing visibility, and connecting.

Looking Ahead

In 2017 we will focus on the long-term financial health of the Academy, by increasing both current use and endowment support, which provides a sustained stream of income. We will continue to offer opportunities to learn about charitable tools for planned giving by conducting seminars on financial and estate planning and regularly communicating...
about this topic. If you are interested in making a planned gift to the NAE, or if you have made a gift provision in your estate plans but not yet notified us, please contact Jamie Killorin, director of gift planning, at 202.334.3833 or JKil@nas.edu so that we can recognize and celebrate your generosity.

Your philanthropic support enables the NAE to have a solid foundation from which to sustain its important projects and spearhead the creation of new and timely programs. The energetic participation of our members has always driven the NAE forward with crucial time, effort, and ideas. Our members are also vital to our fundraising success, both by making financial contributions of their own and by serving as advocates for the NAE and engineering to their peers. We sincerely appreciate your generosity and continued support.

On behalf of the NAE Council, President Dan Mote, and myself, thank you very much for your contributions in 2016. Our supporting members, friends, partner corporations, foundations, government sponsors, and other organizations make all the difference in our ability to educate both national and international policymakers and the public about the value of engineering’s contributions. I am grateful for your contributions and look forward to your continued involvement in 2017.

Corale L. Brierley

2016 Honor Roll of Donors

Annual Giving Societies

The National Academy of Engineering gratefully acknowledges the following members and friends who made charitable contributions to the NAE and those NAE members who supported the Committee on Human Rights, a joint committee of the three academies, during 2016. The collective, private philanthropy of these individuals has a great impact on the NAE and its ability to be a national voice for engineering. We acknowledge contributions made as personal gifts or as gifts facilitated by the donor through a donor-advised fund, matching gift program, or family foundation.

During the 2016 annual meeting, Chairman Gordon England announced the creation of a $100,000 Chairman’s Challenge for Section 1 that he is personally funding and asked others to join him in creating matching gift challenges for each section by the 2017 annual meeting. Donors who participated in the Chairman’s Challenge are noted with the * symbol.

Fran Ligler, a member of the NAE Council, and her husband George pledged $100,000 in 2015 to encourage new and increased giving by Section 2 members for five years, or until the $100,000 goal is reached. Donors who participated in the Ligler Challenge are noted with the ‡ symbol.

The Sanjit K. Mitra Family Challenge encouraged members in the classes of 2013–2016 to support the NAE and our programs. Donors who participated in the Mitra Challenge are noted with the ◊ symbol.

In response to the Chairman’s Challenge, James Truchard gave $100,000 to fund a challenge for Section 7. Donors who participated in the Section 7 Challenge are noted with the % symbol.
### Catalyst Society

<table>
<thead>
<tr>
<th>Amount</th>
<th>Donors</th>
</tr>
</thead>
<tbody>
<tr>
<td>$50,000+</td>
<td>Craig and Barbara Barrett, Ming and Eva Hsieh, Sanjit K. and Nandita Mitra, Andrew and Erna* Viterbi Friends, Gordon Bell, Paul F. Boulos, Nicholas M. Donofrio, James O. Ellis, Jr. and Elisabeth Paté-Cornell, John O. Hallquist, David E. Shaw, Raymond S. Stata, James J. Truchard, Andrew and Erna* Viterbi Friends, John F. McDonnell</td>
</tr>
</tbody>
</table>

### Rosette Society

<table>
<thead>
<tr>
<th>Amount</th>
<th>Donors</th>
</tr>
</thead>
<tbody>
<tr>
<td>$25,000 to $50,000</td>
<td>Gordon Bell, Paul F. Boulos, Nicholas M. Donofrio, James O. Ellis, Jr. and Elisabeth Paté-Cornell, John O. Hallquist, Narayan Murty, David E. Shaw, Christopher B. Galvin</td>
</tr>
</tbody>
</table>

### Challenge Society

<table>
<thead>
<tr>
<th>Amount</th>
<th>Donors</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10,000 to $25,000</td>
<td>Ruth and Ken Arnold, Bharati and Murty Bhavaraju, Barry W. Boehm, Josephine Cheng, Uma Chowdhry, Ross and Stephanie Corotis, Ruth A. David, Lance and Susan Davis, Jeffrey Dean, Olivia and Peter Farrell, Douglas W. and Margaret P. Fuerstenau, Martin E. and Lucinda Glicksman, Robert W. Gore, Paul and Judy Gray, Chad and Ann Holliday, Michael W. Hunkapiller, John and Nancy Junkins, Kent Kresa, Jane and Norman N. Li, Fran and George Ligler, Burn-Jeng Lin, Clayton Daniel and Patricia L. Mote, Ronald and Joan Nordgren, Roberto Padovani, Larry* and Carol Papay, Leonard Pinchuk, Julie and Alton D. Romig, Jr., Jonathan M. Rothberg, Henry and Susan Samueli, Robert E. and Mary L. Schafrik, Richard J. Stegemeier, David W. Thompson, Adrian Zaccaria, Y.H. Gandhi</td>
</tr>
</tbody>
</table>

### Charter Society

<table>
<thead>
<tr>
<th>Amount</th>
<th>Donors</th>
</tr>
</thead>
</table>

---

*Chairman’s Challenge
*Ligler Challenge
*Mitra Challenge
*Section 7 Challenge
*Deceased
Stephen W. Director
Albert A. and Joan Dorman
Elisabeth M. Drake
James J. Duderstadt
Robert and Cornelia Eaton
Farouk El-Baz
Derek Elsworth
Gerard W. Elverum
Iraj Ershaghi
John V. Evans
Robert R. Everett
Thomas E. Everhart
Hans K. Fauske
Robert E. Fenton
Leroy M. Fingerson
Bruce A. Finlayson
Anthony E. Fiorato
Robert E. Fischell
Edith M. Flanigen
Samuel C. Florman
G. David Forney, Jr.
Robert C. "and Marilyn G. Forney
John S. Foster, Jr.
Charles A. Fowler
William L. and Mary Kay Friend
Samuel H. Fuller
Huijuan Gao
Donald P. Gaver
Ronald L. Geer
Arthur Gelb
Arthur and Helen Geoffrion
Louis V. Gerstner, Jr.
Nan and Chuck Geschke
Paul H. Gilbert
Eduardo D. Glandt
George J. Gleghorn
Earnest F. Gloyna
Dan M. Goebel
Arthur L. and Vida F. Goldstein
Mary L. Good
Joseph W. Goodman
W. David Gooyear
Paul E. Gray
Hermann K. Gummel
Eliyahu Harari
James S. Harris, Jr.
Wesley L. Harris
Janina and Siegfried Hecker
Chris T. Hendrickson
John L. Hennessy
Robert and Paula Henry
Janet G. Hering
Grace and Thom Hodgson
Urs Hölzl
Edward E. Hood, Jr.
John R. Howell
Evelyn L. Hu and David R. Clarke
J. Stuart Hunter
Ray R. Irani
Mary Jane Irwin
Irwin and Joan Jacobs
Wilhelmina and Stephen Jaffe
Leah H. Jamieson
George W. Jeffs
James O. Jirsa
Barry C. Johnson
David W. Johnson, Jr.
Michael R. Johnson
Frank and Pam Joklik
Anita K. Jones
Kahle/Austin Foundation
Robert E. Kahn
Eric W. and Karen F. Kaler
Paul and Julie Kaminski
Melvin F. Kanninen
John and Wilma Kasakian
James R. "and Isabelle Katzer
Leon M. Keer
Mary and Howard Kehrli
Chaitan Khosla and Susi Ebert-Khosla
Diana S. and Michael D. King
Judson and Jeanne King
James L. Kirtley
Albert S. Kobayashi
Paul C. Kocher
Robert M. and Pauline W. Koerner
Charles E. Kolb, Jr.
Jindrich Kopecek
Demetrius Koutsofas
Philip T. Krein
Ellen J. Kullman
Derrick M. Kuzak
Louis J. and M. Yvonne De Wolf Lanzerotti
David C. Larbalestier
Shih-Ying Lee
James U. Lemke
Ronald K. Leonard
Frederick J. Leonberger
Helmut List
Jack E. Little
J. David Lowell
William J. MacKnight
Thomas and Caroline Maddock
Asad M., Gohwhtaj, and Jamal Madni
Arunava Majumdar
Thomas J. Malone
Henrique S. Malvar
Hans Mark
David A. Markle
W. Allen Marr
John L. Mason
Dan and Dalia Maydan
Jyotirmoy Mazumder
Kishor C. Mehta
Edward W. Merrill
Richard A. Meserve
Joahim Milberg
Richard B. Miles
Richard K. Miller

Chairman's Challenge
Ligler Challenge
Mitra Challenge
Section 7 Challenge
Deceased
Other Individual Donors

Hiroyuki Abe
H. Norman Abramson*
Hadi Abu-Akeel
Bernard Amadei
Cristina H. Amon
John G. Anderson
Mary P. Anderson
Kristi S. Anseth‡
George E. Apostolakis
Ali S. Argon
Frances H. Arnold
Daniel and Monica Atkins‡
Teresa and Harry Arwater‡
Jamal J. Azar

*Chairman’s Challenge
‡Ligler Challenge
◊Mitra Challenge
§Section 7 Challenge
*Deceased
Donald W. Bahr
Ruzena K. Bajcsy
Clyde and Jeanette Baker
Grigory I. Barenblatt
James E. Barger
Jordan* and Rhoda Baruch
Ray H. Baughman
Zdenek P. Bazant

Marlene and Georges Belfort
Marsha J. Berger
Philip A. Bernstein
Vitelmo V. Bertero

John R. and Pierrette G. Birge
Ilan Asriel Blech
Alfred Blumstein
F. Peter Boer
William J. Boettinger
Lillian C. Borrone
Kevin G. Bowcutt

Jonathan D. Bray
James P. Brill
Emery N. Brown
Howard J. Bruschi
Jack E. Buffington
Robert L. Byer

Anne and John* Cahn
Robert Calderbank
Federico Capasso
Max W. Carbon
E. Dean Carlson
John R. Casani
A. Ray Chamberlain
K.M. Chandy
Douglas M. Chapin
Vernon L. Chartier
Gang and Tracy Chen

Shu Chien
Andrew R. Chraplyvy
Robert P. Clagett
John L. Cleasby
Richard A. Conway
Alan W. Cramb
Lawrence B. Curtis
Ernest L. Daman
Ingrid Daubechies
Joseph M. DeSimone
Frederick H. Dill
Dennis E. Discher
Robert H. Dodds
Irwin Dorros
Earl H. Dowell
E. Linn Draper, Jr.
T. Dixon Dudderar
David A. Dzombak
Peter S. Eagleson
Bruce R. Ellingwood
Richard E. Emmert
Lawrence B. Evans
Robert M. Fano
Katherine W. Ferrara
Essex E. Finney, Jr.
Millard and Barbara Firebaugh
John W. Fisher
Peter T. Flawn
Maria Flytzani-Stefanopoulous
Robert E. Fontana
Harold K.* and Betty A. Forsen
Judson C. French
Eli Fromm
Mauricio Futran
Theodore V. Galambos
Zvi Galil
Jacqueline Gish
Richard D. Gitlin
Herbert Gleiter
Richard J. Goldstein
John B. Goodenough
Roy W. Gould
Robert K. Grasselli
Irene Greif
Gary S. Grest
Ignacio E. Grossmann
Donald J. Haderle
Edward E. Hagenlocker
Carol K. Hall
William J. Hall
Niels Hansen
Mehdi Hatamian
Henry J. Hatch
William A. Hawkins III
Adam Heller
Martin Hellman
Arthur H. Heuer
Mary C. Hipwell
George J. Hirasaki
Peter B. Hirsch
John P. Hirth
Chih-Ming Ho
David and Susan Hodges
Allan S. Hoffman
Richard Hogg
Davorin D. Hrovat
Thomas J.R. Hughes
Arthur E. Humphrey
Salim M. Ibrahim
Izzat M. Idriss
Kenichi Iga
Jeremy Isenberg
Kenji Ishihara
Tatsuo Itoh
Andrew Jackson and Lillian Rangel
Linos J. Jacovides
Anil K. Jain
Paul C. Jennings
Donald L. Johnson
Marshall G. Jones
Chanrashekhar Joshi
Norman P. Jouppi
Ahsan Kareem
Kristina B. Katsaros
Kenneth H. Keller
Marilyn and Justin Kerwin
Timothy L. Killeen
Sung Wan Kim
Robert L. Kleinberg
Carl C. Koch
Max A. Kohler
Bill and Ann Koros
Roger B. and Barbara Nunn Krieger
Fikri J. Kuchuk
Thomas F. Kuech
Richard T. Lahey, Jr.
Bruce M. Lake
James L. Lammie
David A. Landrige
Robert C. Lanphier III
Ronald G. Larson
Alan Lawley
Ann L. Lee
Margaret A. LeMone
Johanna M.H. LeVeel
Sengers
Paul A. Libby
Peter W. Likins
Kuo-Nan Liou
Nathan and Barbara Liskov
Daniel P. Loucks
Andrew J. Lovinger
William R. Lucas
Cecil Lue-Hing
Mark and Mary Lundstrom
Verne L. Lynn
J. Ross Macdonald
Malcolm MacKinnon III
Alfred U. MacRae
Subhash and Sushma Mahajan
James W. Mar
William F. Marcuson III
Robert C. Marini
Nelson Martins
David K. Matlock
Robert D. Maurer
William C. Maurer
Robert and Norah McMeeking
Terence P. McNulty
Alan L. McWhorter
Antonios G. Mikos and Lydia Kavraki

*Chairman’s Challenge
†Ligler Challenge
◊Mitra Challenge
§Section 7 Challenge
*Deceased
James A. Miller
Warren F. Miller, Jr.
Carl L. Monismith
John W. Morris
A. Stephen Morse
George Muellner
Earl M. Murman
Devarayasingamudram R. Nagaraj
R. Shankar Nair
Hyda S. Napadensky
David Nash
Alan Needleman
Stuart O. Nelson
Joseph H. Newman
J. Tinsley Oden
Babatunde and Anna Ogunnaike
Donald R. Olander
Robert S. O’Neil
Elaine S. Oran
David H. Pai
Athanassios Z. Panagiotopoulos
Morton B. Panish
Stavros S. Papadopoulos
Bradford W. and Virginia W. Parkinson
Donald R. Paul
Harold W. Paxton
Nicholas A. Peppas
Richard H. Petersen
George M. Pharr
Mark R. Pinto
Karl S. Pister
John W. and Susan M. Poduska
Harry G. Poulos
Michael Prats
Ronald F. Probstein
Charles W. Pryor, Jr.
Roberta and Edwin Przybylowicz
Robert A. Rapp
L. Rafael Reif
John R. Rice
Bruce E. Rittmann
Jerome G. Riva
Leslie E. Robertson and SawTeen See
Virginia M. Rometty
Arye Rosen
Howie Rosen and Susan Doherty
Kenneth M. Rosen
Donald E. Ross
William B. Rouse
B. Don and Becky Russell
Joseph C. Salamone
Peter W. Sauer
Robert F. Sawyer
Ronald W. Schafer
George W. Scherer
Richard Scherrer
Jerald L. Schnoor
William R. Schowalter
Walter J. Schrenk
Albert and Susan Schultz
Mischa Schwartz
Balraj Sehgal
Robert J. Serafin
F. Stan Settles
Don W. Shaw
Ben A. Shneiderman
Neil G. Siegel
Arnold H. Silver
Peter G. Simpkins
Jack M. Sipress
Alvy Ray Smith
Gurindar S. Sohi
Stuart L. Soled
Soroosh Sorooshian
Pol D. Spanos
George L. Stegeman
Robert L. Steigerwald
Thomas G. Stephens
Kenneth H. Stokoe
Howard and Valerie Stone
Brian Stott
Richard G. Strauch
Gerald B. Stringfellow
Stanley C. Suboleski
Yasuhiro Suematsu
James M. Symons
Rodney J. Tabaczynski
Daniel M. Tellep
Lewis M. Terman
Leonard K. Thomas
Neil E. Todreas
Alvin Trivelpiece
Marshall P. Tulin
Theodore Van Duzer
Walter G. Vincenti
Irving T. Waaland
Wallace R. Wade
Steven J. Wallach
C. Michael Walton
John D. Warner
Michael S. Waterman
John T. and Diane M. Watson
Julia and Johannes Weertman
Robert J. Weimer
Sheldon Weinbaum
Sheldon Weing
Jasper A. Welch, Jr.
J. Turner Whitted
Kaspar J. Willam
Sheldon Weinig
J. Turner Whitted
Kaspar J. Willam
Sharon L. Wood
Richard David Woods
David A. Woolhiser
James J. Wynne
Eli Yablonovitch
Michael I. Yarmovych
Ajit P. Yoganathan
Les Youd
Laurence R. Young
Paul Zia
Steven J. Zinkle
Dusan S. Zrnic
Friends
Julie Ajinkya
Utpal Bhattacharya
Clara K. Ellert
Harold and Arlene Finger
Joan R. Finnie
Gratia H. Griffith
Joan Hulburt
Erica H. Ling
Barbara Mason
Kathryn Mickunas
Amy Misera
Joanne Morse
Michael Murphy and Karen Gundersen
Radka Z. Nebesky
Andrew Oakley
Sallie O’Neill
Joanne Roehm
Kiera Ryckman
Georgia Scordelis
Verna W. Spinrad
Elizabeth W. Toor
Marianne Tropp and Chris Loughner
Jennifer Warner
Rhoda A.M. Weisz
Sarah Widner-Hess
Stacey Williams
Joan R. Zaorski

Chairman’s Challenge
Ligler Challenge
Mitra Challenge
Section 7 Challenge
Deceased
Tributes

In Memory of Milind and Raj Ajinkya – Julie Ajinkya
In Memory of Steven Zay Azar – Jamal J. Azar
In Memory of Jordan Baruch – Rhoda Baruch
In Memory of Robert R. Berg – Josephine F. Berg
In Memory of Erich Bloch – Gordon Bell, Radka Nebesky
In Memory of Alfred R. DeLeo – Stacey Williams
In Memory of Greta Duschinsky – Marlene and Georges Belfort
In Memory of Harry and Norma Fineblum – Leonard Pinchuk
In Memory of Sheldon K. Friedlander – Marjorie R. Friedlander
In Memory of Maurice Fuerstenau – Douglas W. and Margaret P. Fuerstenau
In Memory of William Griffith – Gratia H. Griffith
In Memory of Howard St. Clair Jones Jr. – Evelyn S. Jones
In Memory of Gibran Kareem – Ahsan Kareem
In Memory of Frederick F. Ling – Erica H. Ling
In Memory of Edward A. Mason – Barbara Mason
In Memory of Dale Myers – Richard H. Petersen
In Memory of Jenney Resch – Joan R. Zaorski
In Memory of Ernest Smerdon – Soroosh Sorooshian
In Memory of Edith Smith – Alvy Ray Smith
In Memory of Chang-Lin Tien – Arunava Majumdar
In Memory of Chuck Vest – Gang and Tracy Chen, Jyotirmoy Mazumder
In Memory of Dixie Woods – Richard David Woods
In Honor of Kristen Allison – Joanne Roehm
In Honor of Michelle Goodyear – W. David Goodyear
In Honor of Kandice Gray – Kathryn Mickunas
In Honor of Brittney Mohr – Kiera Ryckman
In Honor of Prof. John Quinn – Montgomery and Ann Alger

Loyalty Society

In recognition of members and friends who have made gifts to the National Academies of Sciences, Engineering, and Medicine for at least 20 years. We acknowledge contributions made as personal gifts or as gifts facilitated by the donor through a donor-advised fund, matching gift program, or family foundation. Names in bold are NAE members.

Herbert L. Abrams*
H. Norman Abramson
Andreas and Juana Acrivos
Bruce and Betty Alberts
Clarence R. Allen
Barbara W. Alpert
Marilynn and Charles A. Amann
Wyatt W. Anderson
John C. Angus
Frank F. Aplan
Edward M. Arnett
Daniel L. Azarnoff
Donald W. Bahr
Jack D. Barchas
Jeremiah A. Barondess
Stephen D. Bechtel, Jr.
John C. Beck*
Richard E. Behrman
Gordon Bell
Leslie Z. Benet
Paul Berg
Kenneth L. Berns
Diane and Norman Bernstein
Stuart Bondurant and Susan Ehringhaus
Kathleen and H. Kent Bowen
Lewis M. Branscomb
John and Sharon Brauman
W.F. Brinkman
Alan C. Brown
Donald D. Brown
Harold Brown
Kristine L. Bueche
Jack E. Buffington
George* and Virginia Bugliarello
William B. Carey
David R. and Jacklyn A. Challoner
Purnell W. Choppin
James McConnell Clark
John L. Cleasby
John A. Clements
Linda Hawes Clever
Michael D. Coe
Richard A. Conway
Max D. Cooper
Linda A. Cozzarelli
Pedro M. Cuatrecasas
Lawrence B. Curtis
William H. Danforth
Igor B. Dawid
Mary and Raymond Decker
Roman W. DeSanctis
Nicholas M. Donofrio

*Deceased
Irwin Dorros  
W.G. Ernst  
Harold J. Fallon  
Gary Felsenfeld  
Harvey V. Fineberg and Mary E. Wilson  
Tobie and Daniel J. Fink  
Samuel C. Florman  
Robert C.* and Marilyn G. Forney  
Harold K.* and Betty Forsen  
T. Kenneth Fowler  
Hans and Verena Frauenfelder  
Carl Frieden  
Theodore V. Galambos  
Joseph G. Gall  
Ronald L. Geer  
E. Peter Geiduschek  
David V. Goeddel  
Joseph W. Goodman  
Richard M. Goody  
Paul E. Gray  
Shirley and Harry Gray  
Robert B. Griffiths  
Michael Grossman  
Adam Heller  
Jane E. Henney and Robert Graham  
Ernest M. Henley  
David and Susan Hodges  
Edward E. Hood, Jr.  
Joseph F. Hoffman  
William N. Hubbard, Jr.  
J. David Jackson*  
André T. Jagendorf  
Robert L. and Anne K. James  
Anita K. Jones  
Richard V. Kadison  
Samuel L. Katz and Catherine M. Wilfert  
Seymour J. Klebanoff*  
Max A. Kohler  
James S. and Elinor G.A. Langer  
Louis J. and M. Yvonne De Wolf Lanzerotti  
Gerald and Doris Laubach  
Judith R. Lave  
Cynthia and Robert Lawrence  
Johanna M.H. Levelt Sengers  
Robert G. Loewy  
Thomas and Caroline Maddock  
Anthony P. Mahowald  
Vincent T. Marchesi  
Hans Mark  
James F. Mathis  
Robert D. Maurer  
Charles A. McCallum  
Christopher F. McKee  
Mortimer Mishkin  
Peter B. Moore  
Joel Moses  
Arno G. Motulsky  
John H. Moxley III  
Elaine and Gerald Nadler  
Jaya and Venky Narayamurti  
Philip and Sima Needelman  
Robert M. and Marilyn R. Nerem  
Elena and Stuart Nightingale  
Ronald and Joan Nordgren  
Peter O’Donnell, Jr.  
Gilbert S. Omenn and Martha A. Darling  
Gordon H. Orians  
George W. Parshall  
Thomas K. Perkins  
Gordon H. Pettengill  
Frank Press  
Donald E. Procknow*  
Simon Ramo*  
Janet and Lester* Reed  
Jerome G. Rivard  
Maxine L. Savitz  
R. Duncan* and Carolyn Scheer Luce  
Gerold L. Schiebler  
Richard M. Schoen  
William R. Schowalter  
F. Stan Settles  
Maxine F. Singer  
Raymond S. Staats  
Joan A. Steitz  
Thomas A. Steitz  
Rosemary A. Stevens  
Lubert and Andrea Stryer  
F. William Studier  
Paul and Pamela Talay  
Charlotte and Morris Tanenbaum  
Jaya and Venky Narayamurti  
Philip and Sima Needelman  
Robert M. and Marilyn R. Nerem  
Elena and Stuart Nightingale  
Ronald and Joan Nordgren  
Peter O’Donnell, Jr.  
Gilbert S. Omenn and Martha A. Darling  
Gordon H. Orians  
George W. Parshall  
Thomas K. Perkins  
Gordon H. Pettengill  
Frank Press  
Donald E. Procknow*  
Simon Ramo*  
Janet and Lester* Reed  
Jerome G. Rivard  
Maxine L. Savitz  
R. Duncan* and Carolyn Scheer Luce  
Gerold L. Schiebler  
Richard M. Schoen  
William R. Schowalter  
F. Stan Settles  
Maxine F. Singer  
Raymond S. Staats  
Joan A. Steitz  
Thomas A. Steitz  
Rosemary A. Stevens  
Lubert and Andrea Stryer  
F. William Studier  
Paul and Pamela Talay  
Charlotte and Morris Tanenbaum  
Jaya and Venky Narayamurti  
Philip and Sima Needelman  
Robert M. and Marilyn R. Nerem  
Elena and Stuart Nightingale  
Ronald and Joan Nordgren  
Peter O’Donnell, Jr.  
Gilbert S. Omenn and Martha A. Darling  
Gordon H. Orians  
George W. Parshall  
Thomas K. Perkins  
Gordon H. Pettengill  
Frank Press  
Donald E. Procknow*  
Simon Ramo*  
Janet and Lester* Reed  
Jerome G. Rivard  
Maxine L. Savitz  
R. Duncan* and Carolyn Scheer Luce  
Gerold L. Schiebler  
Richard M. Schoen  
William R. Schowalter  
F. Stan Settles  
Maxine F. Singer  
Raymond S. Staats  
Joan A. Steitz  
Thomas A. Steitz  
Rosemary A. Stevens  
Lubert and Andrea Stryer  
F. William Studier  
Paul and Pamela Talay  
Charlotte and Morris Tanenbaum  
Jaya and Venky Narayamurti  
Philip and Sima Needelman  
Robert M. and Marilyn R. Nerem  
Elena and Stuart Nightingale  
Ronald and Joan Nordgren  
Peter O’Donnell, Jr.  
Gilbert S. Omenn and Martha A. Darling  
Gordon H. Orians  
George W. Parshall  
Thomas K. Perkins  
Gordon H. Pettengill  
Frank Press  
Donald E. Procknow*  
Simon Ramo*  
Janet and Lester* Reed  
Jerome G. Rivard  
Maxine L. Savitz  
R. Duncan* and Carolyn Scheer Luce  
Gerold L. Schiebler  
Richard M. Schoen  
William R. Schowalter  
F. Stan Settles

**Lifetime Giving Societies**

We gratefully acknowledge the following members and friends who have made generous charitable lifetime contributions. Their collective, private philanthropy enhances the impact of the academies as advisor to the nation on issues of science, engineering, and medicine.

**Einstein Society**

In recognition of members and friends who have made lifetime contributions of $100,000 or more to the National Academy of Sciences, the National Academy of Engineering, or the National Academy of Medicine. We acknowledge contributions made as personal gifts or as gifts facilitated by the donor through a donor-advised fund, matching gift program, or family foundation. Names in bold are NAE members.

*Deceased
<table>
<thead>
<tr>
<th>Amount</th>
<th>Donor Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 million or more</td>
<td>Arnold and Mabel Beckman*, Bernard M. Gordon</td>
</tr>
<tr>
<td></td>
<td>Fred Kavli*, Daniel E. Koshland, Jr.<em>, George P. Mitchell</em></td>
</tr>
<tr>
<td></td>
<td>Raymond and Beverly Sackler</td>
</tr>
<tr>
<td></td>
<td>James H. and Marilyn Simons</td>
</tr>
<tr>
<td>$5 million to $10 million</td>
<td>Donald L. Bren, William R. and Rosemary B. Hewlett*</td>
</tr>
<tr>
<td></td>
<td>Peter O'Donnell, Jr., Dame Jillian Sackler</td>
</tr>
<tr>
<td>$1 million to $5 million</td>
<td>Bruce and Betty Alberts, Richard and Rita Atkinson</td>
</tr>
<tr>
<td></td>
<td>Norman R. Augustine Craig and Barbara Barrett Jordan* and Rhoda Baruch</td>
</tr>
<tr>
<td></td>
<td>Stephen D. Bechtel, Jr., Harry E. Bovay, Jr.*, Harvey V. Fineberg and Mary E. Wilson</td>
</tr>
<tr>
<td></td>
<td>Penny and Bill George*, George Family Foundation</td>
</tr>
<tr>
<td></td>
<td>Cecil H. Green*, Michael and Sheila Held*</td>
</tr>
<tr>
<td></td>
<td>Ming and Eva Hsieh*, Irwin and Joan Jacobs</td>
</tr>
<tr>
<td></td>
<td>Kenneth A. Jonsson*, Tillie K. Lubin*</td>
</tr>
<tr>
<td></td>
<td>John F. McDonnell</td>
</tr>
<tr>
<td></td>
<td>The Ambrose Monell Foundation Gordon and Betty Moore</td>
</tr>
<tr>
<td></td>
<td>Philip and Sima Needleman</td>
</tr>
<tr>
<td></td>
<td>Robert* and Mayari Pritzker</td>
</tr>
<tr>
<td></td>
<td>Richard L. and Hinda G. Rosenthal*</td>
</tr>
<tr>
<td></td>
<td>Jack W. and Valerie Rowe</td>
</tr>
<tr>
<td>$500,000 to $1 million</td>
<td>Rose-Marie and Jack R.<em>, Anderson John and Elizabeth Armstrong, Kenneth E. Behring, Gordon Bell, Elkan R.</em> and Gail F. Blout, Carson Family Charitable Trust, Charina Endowment Fund</td>
</tr>
<tr>
<td></td>
<td>Ralph J.* and Carol M. Cicerone</td>
</tr>
<tr>
<td></td>
<td>James McConnell Clark, Henry David*</td>
</tr>
<tr>
<td></td>
<td>Richard Evans*</td>
</tr>
<tr>
<td></td>
<td>Eugene Garfield Foundation</td>
</tr>
<tr>
<td></td>
<td>Theodore Geballe</td>
</tr>
<tr>
<td></td>
<td>William T.* and Catherine Morrison Golden</td>
</tr>
<tr>
<td></td>
<td>Alexander Hollaender*</td>
</tr>
<tr>
<td></td>
<td>Thomas V. Jones*</td>
</tr>
<tr>
<td></td>
<td>Cindy and Jeong Kim*</td>
</tr>
<tr>
<td></td>
<td>Ralph and Claire Landau*</td>
</tr>
<tr>
<td></td>
<td>Asta and William W. Lang*</td>
</tr>
<tr>
<td></td>
<td>Ruben F.* and Donna Mettler</td>
</tr>
<tr>
<td></td>
<td>Dane* and Mary Louise Miller</td>
</tr>
<tr>
<td></td>
<td>Oliver E. and Gerda K. Nelson*</td>
</tr>
<tr>
<td>$250,000 to $500,000</td>
<td>W.O. Baker*, Warren L. Batts, Clarence S. Coe*, Jerome H.* and Barbara N. Grossman, William R. Jackson*</td>
</tr>
<tr>
<td></td>
<td>Robert L. and Anne K. James</td>
</tr>
<tr>
<td></td>
<td>Mary and Howard* Kehrl</td>
</tr>
<tr>
<td></td>
<td>Robin K. and Rose M. McGuire</td>
</tr>
<tr>
<td></td>
<td>Janet and Richard M.* Morrow</td>
</tr>
<tr>
<td></td>
<td>Ralph S. O’Connor</td>
</tr>
<tr>
<td></td>
<td>Kenneth H. Olsen*</td>
</tr>
<tr>
<td></td>
<td>Ann and Michael Ramage</td>
</tr>
<tr>
<td></td>
<td>Simon Ramo*</td>
</tr>
<tr>
<td></td>
<td>Anne and Walt Robb</td>
</tr>
<tr>
<td></td>
<td>Stephen* and Anne Ryan</td>
</tr>
<tr>
<td></td>
<td>Henry and Susan Samueli</td>
</tr>
<tr>
<td></td>
<td>H.E. Simmons*</td>
</tr>
<tr>
<td></td>
<td>Judy Swanson</td>
</tr>
<tr>
<td></td>
<td>Ted Turner</td>
</tr>
<tr>
<td></td>
<td>Leslie L. Vadasz</td>
</tr>
<tr>
<td></td>
<td>Martha Vaughan</td>
</tr>
<tr>
<td></td>
<td>Charles M.* and Rebecca</td>
</tr>
<tr>
<td></td>
<td>M. Vest</td>
</tr>
</tbody>
</table>

*Deceased
$100,000 to $250,000

Holt Ashley*  Francisco J. and Hana Ayala
William F. Ballhaus, Sr.*  Thomas D.* and Janice H. Barrow
H.H. and Eleanor F. Barschall*  Daniel and Frances Berg
Elwyn and Jennifer Berlekamp  Diane and Norman Bernstein
Bharati and Murty Bhavaraju  Erich Bloch*
Barry W. Boehm  Paul F. Boulos  David G. Bradley
Lewis M. Branscomb  Sydney Brenner  George* and Virginia Bugliarello
Malin Burnham  Ursula Burns and Lloyd Bean
John and Assia Cioffi  Paul Citron and Margaret Carlson Citron
A. James Clark*  G. Wayne Clough
W. Dale and Jeanne C. Compton*  John D. Corbett*
Ross and Stephanie Corotis  Lance and Susan Davis
Roman W. DeSanctis  Robert and Florence Deutsch
Nicholas M. Donofrio  Paul M. Doty*
Charles W. Duncan, Jr.  Ruth and Victor Dzau
George and Maggie Eads  Robert and Cornelia Eaton
James O. Ellis, Jr. and Elisabeth Paté-Cornell
Dotty and Gordon England  Emanuel and Peggy Epstein
Olivia and Peter Farrell  Michiko So* and Lawrence Finegold
Tobie and Daniel J.* Fink  George and Ann Fisher
Robert C.* and Marilyn G. Forney  Harold K.* and Betty Forsen
William L. and Mary Kay Friend  Christopher Galvin
William H. and Melinda E. Gates III  Nan and Chuck Geschke
Jack and Linda Gill  Martin E. and Lucinda Glicksman
George and Christine Gloeckler  Christa and Detlef Glose
Avram Goldstein*  Robert W. Gore
Paul and Judy Gray  Corbin Gwaltney
John O. Hallquist  Margaret A. Hamburg and Peter F. Brown
William M. Haney III  George and Daphne Hatsopoulos
John L. Hennessey  Jane Hirsh  Chad and Ann Holliday
Michael W. Hunkapiller  M. Blakeman Ingle
Richard B. Johnston, Jr.  Anita K. Jones
Trevor O. Jones  Thomas Kailath  Yuet Wai and Alvera Kan
Leon K. and Olga Kirchmayer*  Frederick A. Klingenstein
William I. Koch  Gail F. Koshland  Jill Howell Kramer
Kent Kresa  John W. Landis*  Janet and Barry Lang
Ming-wai Lau  Gerald and Doris Laubach
David M.* and Natalie Lederman
Bonnie Berger and Frank Thomson Leighton
Frances and George Ligler  Whitney and Betty MacMillan
Asad M., Gowhartaj, and Jamal Madni
Davis L. Masten and Christopher Ireland
Roger L. McCarthy  William W. McGuire  Burt and Deedee McMurtry
G. William* and Ariadna Miller
Ronald D. Miller  Stanley L. Miller*
Sanjit K. and Nandita Mitra
Joe and Glenna Moore  David* and Lindsay Morgenthaler
Clayton Daniel and Patricia L. Mote
Ellen and Philip Neches
Susan and Franklin M. Orr, Jr.
David Packard*  Charles and Doris Pankow*
Larry* and Carol Papay
Jack S. Parker*  Edward E. Penhoet
Allen E.* and Marilynn Puckett
Richard F. and Terri W. Rashid  Alexander Rich*
Ronald L. Rivest  Matthew L. Rogers and Swati Mylavarapu
Henry M. Rowan*  Joseph E. and Anne P. Rowe*
Jonathan J. Rubinstein  Maxine L. Savitz
Walter Schup*  Wendy and Eric Schmidt
David E. Shaw  Richard P. Simmons
Robert F. and Lee S. Sproull
Georges C. St. Laurent, Jr.  Arnold and Constance Stancell
Edward C. Stone
John and Janet Swanson  Charlotte and Morris Tanenbaum
Peter and Vivian Teets
James M. Tien and Ellen S. Weston
Gary and Diane Tooker
James J. Truchard
John C. Wall  Robert and Joan Wertheim
Robert M.* and Mavis E. White
John C. Whitehead*  Jean D. Wilson
Wm. A. Wulf  Ken Xie
Tachi and Leslie Yamada  Adrian Zaccaria
Alejandro Zaffaroni*  Janet and Jerry Zucker
Anonymous (2)

*Deceased
# Golden Bridge Society

In recognition of NAE members and friends who have made lifetime contributions totaling $20,000 to $100,000. We acknowledge contributions made as personal gifts or as gifts facilitated by the donor through a donor-advised fund, matching gift program, or family foundation. Names in bold are NAE members.

### $75,000 to $100,000

<table>
<thead>
<tr>
<th>Name(s)</th>
<th>Name(s)</th>
<th>Name(s)</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruth A. David</td>
<td>Rita Vaughn and</td>
<td>Johanna M.H. Levelt</td>
<td>Ronald and Joan</td>
</tr>
<tr>
<td>Thomas E. Everhart</td>
<td>Theodore C.* Kennedy</td>
<td>Sengers</td>
<td>Nordgren</td>
</tr>
<tr>
<td>Paul and Julie Kaminski</td>
<td></td>
<td></td>
<td>Richard J. Stegemeier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### $50,000 to $75,000

<table>
<thead>
<tr>
<th>Name(s)</th>
<th>Name(s)</th>
<th>Name(s)</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kristine L. Bueche</td>
<td>Robert E. Kahn</td>
<td>Murty</td>
<td>Warren G. Schlinger</td>
</tr>
<tr>
<td>Corbett Caudill</td>
<td>John and Wilma</td>
<td>Cynthia J. and Norman A. Nadel</td>
<td>Leo John* and Joanne Thomas</td>
</tr>
<tr>
<td>William Cavanaugh</td>
<td>Kassakian</td>
<td>Jaya and Venky</td>
<td>Julia and Johannes</td>
</tr>
<tr>
<td>Joseph V. Charyk*</td>
<td>Jane and Norman N. Li</td>
<td>Narayananurti</td>
<td>Weertman</td>
</tr>
<tr>
<td>Sunlin Chou</td>
<td>Darla and George E.* Mueller</td>
<td>John Neerhout, Jr.</td>
<td>Sheila E. Widnall</td>
</tr>
<tr>
<td>The Crown Family</td>
<td>Jane and Alan R. Mulally</td>
<td>Roberto Padovani</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### $20,000 to $50,000

<table>
<thead>
<tr>
<th>Name(s)</th>
<th>Name(s)</th>
<th>Name(s)</th>
<th>Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andreas and Juana</td>
<td>Rodney A. Brooks</td>
<td>Bonnie and Donald N.* Frey</td>
<td>Bettie and Kenneth F.* Holtby</td>
</tr>
<tr>
<td>Alice Merner Agogino</td>
<td>Selim A. Chacour</td>
<td>Richard L. and Lois E. Garwin</td>
<td></td>
</tr>
<tr>
<td>Clarence R. Allen</td>
<td>Chau-Chyun Chen</td>
<td>Arthur and Helen</td>
<td></td>
</tr>
<tr>
<td>Valerie and William A. Anders</td>
<td>Josephine Cheng</td>
<td>Geoffrion</td>
<td></td>
</tr>
<tr>
<td>John and Pat Anderson</td>
<td>Uma Chowdhry</td>
<td>Louis V. Gerstner, Jr.</td>
<td></td>
</tr>
<tr>
<td>Seta and Diran Apelian</td>
<td>Joseph M. Colucci</td>
<td>Paul H. Gilbert</td>
<td></td>
</tr>
<tr>
<td>Ruth and Ken Arnold</td>
<td>Rosemary L. and Harry M. Conger</td>
<td>Eduardo D. Glandt</td>
<td></td>
</tr>
<tr>
<td>Kamla* and Bishnu S. Atal</td>
<td>Malcolm R. Currie</td>
<td>Arthur L. and Vida F. Goldstein</td>
<td></td>
</tr>
<tr>
<td>Nadine Aubry and John L. Batton</td>
<td>David and Susan Daniel</td>
<td>Mary L. Good</td>
<td></td>
</tr>
<tr>
<td>Ken Austin</td>
<td>Ruth M. Davis* and Benjamin Lohr</td>
<td>Joseph W. Goodman</td>
<td></td>
</tr>
<tr>
<td>Clyde and Jeanette Baker</td>
<td>Jeffrey Dean</td>
<td>Albert G. Greenberg</td>
<td></td>
</tr>
<tr>
<td>William F. Banholzer</td>
<td>Pablo G. Debenedetti</td>
<td>Delon Hampton</td>
<td></td>
</tr>
<tr>
<td>David K. Barton</td>
<td>Tom and Bettie Deen</td>
<td>Wesley L. Harris</td>
<td></td>
</tr>
<tr>
<td>Becky and Tom Bergman</td>
<td>Mary P. and Gerald P.* Dinneen</td>
<td>Janina and Siegfried Hecker</td>
<td></td>
</tr>
<tr>
<td>R. Byron Bird</td>
<td>E. Linn Draper, Jr.</td>
<td>Robert and Darlene</td>
<td></td>
</tr>
<tr>
<td>Diane and Samuel W. Bodman</td>
<td>Mildred S. Dresselhaus*</td>
<td>Hermann</td>
<td></td>
</tr>
<tr>
<td>Kathleen and H. Kent Bowen</td>
<td>James J. Duderstadt</td>
<td>David and Susan Hodges</td>
<td></td>
</tr>
<tr>
<td>Corale L. Brierley</td>
<td>Gerard W. Elverum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>James A. Brierley</td>
<td>Stephen N. Finger</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Edith M. Flanigan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Deceased</td>
<td>Samuel C. Florman</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Deceased
Heritage Society

In recognition of members and friends who have included the National Academy of Sciences, National Academy of Engineering, or National Academy of Medicine in their estate plans or who have made some other type of planned gift to the Academies. Names in bold are NAE members.

Andreas and Juana Acrivos
Gene M. and Marian Amdahl
Betsy Ancker-Johnson
John C. Angus
John and Elizabeth Armstrong
Norman R. Augustine
Jack D. Barchas
Harrison H. and Catherine C. Barrett
Stanley Baum
Clyde J. Behney
Elisabeth Belmont
Daniel and Frances Berg
Paul Berg
Elkan R.* and Gail F. Blout
Enriqueta C. Bond
Daniel Branton
Robert and Lillian Brent
Arogyaswami J. Paulraj
Paul S. Peercy
Lee and Bill Perry
Donald E. Petersen
Julia M. Phillips and John A. Connor
Dennis J. Picard
John W. and Susan M. Poduska
Donald E. Procknow
Henry R. Rachford, Jr.
Joy and George* Rathmann
Buddy D. Ratner
Eberhardt* and Deedee Rechtin
Kenneth and Martha Reifsnider
Julie and Alton D.
Romig, Jr.
Howie Rosen and Susan Doherty
Vinod K. Sahney
Steve* and Kathyrn Sample
Jerry Sanders III
Linda S. Sanford
Robert E. and Mary L.
Schafrik
Ronald V. Schmidt
Roland W. Schmitt
Martin B. and Beatrice E.
Sherwin
Alfred Z. Spector and Rhonda G. Kost
David B. and Virginia H.
Spencer
Henry E. Stone
Gaye and Alan Taub
Rosemary and George Tchobanglous

Daniel M. Tellep
David W. Thompson
James A. Trainham
Linda D. Waters
Raymond Viskanta
Robert and Robyn Wagoner
Daniel I. Wang
Albert R.C. and Jeannie Westwood
David A. Whelan
Willis S. White, Jr.
John J. Wise
Edgar S. Woolard, Jr.
A. Thomas Young
Young
Elia A. Zerhouni
Anonymous (1)

John G. Hildebrand and Gail D. Burd
Nancy S. and Thomas S.
Inui
Richard B. Johnston, Jr.
Anita K. Jones
Jerome Kagan
Diana S. and Michael D.
King
Asta and William W.
Lang*
Norma M. Lang
Daniel P. Loucks
R. Duncan* and Carolyn Scheer Luce
Thomas and Caroline Maddock
Artur Mager*
Pat and Jim McLaughlin
Jane Menken
Arno G. Motulskey
Van and Barbara Mow

*Deceased
Foundations, Corporations, and Other Organizations

Lifetime

In recognition of foundations, corporations, and other organizations that have given gifts or grants totaling $1 million or more to the National Academy of Sciences, the National Academy of Engineering, or the National Academy of Medicine. Names in bold have supported the NAE.

<table>
<thead>
<tr>
<th>$25 million or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnegie Corporation of New York</td>
</tr>
<tr>
<td>The Ford Foundation</td>
</tr>
<tr>
<td>The Bill &amp; Melinda Gates Foundation</td>
</tr>
<tr>
<td>The Robert Wood Johnson Foundation</td>
</tr>
<tr>
<td>The Kavli Foundation</td>
</tr>
<tr>
<td>W.M. Keck Foundation</td>
</tr>
<tr>
<td>W.K. Kellogg Foundation</td>
</tr>
<tr>
<td>The Koshland Foundation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$10 million to $25 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arnold and Mabel Beckman Foundation</td>
</tr>
<tr>
<td>The Charles Stark Draper Laboratory</td>
</tr>
<tr>
<td>The William and Flora Hewlett Foundation</td>
</tr>
<tr>
<td>Howard Hughes Medical Institute</td>
</tr>
<tr>
<td>The John D. and Catherine T. MacArthur Foundation</td>
</tr>
<tr>
<td>The Andrew W. Mellon Foundation</td>
</tr>
<tr>
<td>The Cynthia and George Mitchell Foundation</td>
</tr>
<tr>
<td>Raymond and Beverly Sackler Foundation</td>
</tr>
<tr>
<td>Simons Foundation</td>
</tr>
<tr>
<td>Alfred P. Sloan Foundation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$5 million to $10 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael and Susan Dell Foundation</td>
</tr>
<tr>
<td>The Grainger Foundation</td>
</tr>
<tr>
<td>The Irvine Company</td>
</tr>
<tr>
<td>Kaiser Permanente</td>
</tr>
<tr>
<td>Merck &amp; Company, Inc.</td>
</tr>
<tr>
<td>Gordon and Betty Moore Foundation</td>
</tr>
<tr>
<td>The Pew Charitable Trusts</td>
</tr>
<tr>
<td>The Rockefeller Foundation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$1 million to $5 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aetna Foundation</td>
</tr>
<tr>
<td>American Board of Family Medicine</td>
</tr>
<tr>
<td>American Cancer Society</td>
</tr>
<tr>
<td>American Legacy Foundation</td>
</tr>
<tr>
<td>American Public Transportation Association</td>
</tr>
<tr>
<td>America’s Health Insurance Plans Foundation</td>
</tr>
<tr>
<td>AstraZeneca Pharmaceuticals LP</td>
</tr>
<tr>
<td>AT&amp;T Corporation</td>
</tr>
<tr>
<td>Laura and John Arnold Foundation</td>
</tr>
<tr>
<td>The Atlantic Philanthropies (USA)</td>
</tr>
<tr>
<td>Atkinson Family Foundation</td>
</tr>
<tr>
<td>The Bill &amp; Melinda Gates Foundation</td>
</tr>
<tr>
<td>The Robert Wood Johnson Foundation</td>
</tr>
<tr>
<td>The Cynthia and George Mitchell Foundation</td>
</tr>
<tr>
<td>Atkinson Family Foundation</td>
</tr>
<tr>
<td>The Atlantic Philanthropies (USA)</td>
</tr>
<tr>
<td>Craig &amp; Barbara Barrett Foundation</td>
</tr>
<tr>
<td>Battelle</td>
</tr>
</tbody>
</table>

*Deceased
Annual
In recognition of foundations, corporations, or other organizations that made gifts or grants to support the National Academy of Engineering in 2016.

The Agouron Institute
Avid Solutions Industrial Process Control
Baxter International Foundation Matching Gift Program
Bell Family Foundation
Benevity Community Impact Fund
Bodman Family Foundation
The Boeing Charitable Trust
The Boeing Company
Boeing PAC Match Program
Boer Family Foundation
Branscomb Family Foundation
Castaing Family Foundation
Chevron Corporation
Chevron Matching Employee Funds
Community Foundation Silicon Valley
Cummins, Inc.
Albert and Joan Dorman Family Foundation
The Charles Stark Draper Laboratory
Egon Zehnder
Ernst & Young
ExxonMobil Corporation
ExxonMobil Foundation
Ford Motor Company Foundation for Child Development
Foundation for Food and Agriculture Research
General Electric Company
General Motors Company
GlaxoSmithKline
Google Inc.
William T. Grant Foundation
Great Lakes Protection Fund
The Greenwall Foundation
The John A. Hartford Foundation
Leona M. and Harry B. Helmsley Foundation
Hewlett-Packard Company
Hsieh Family Foundation
Intel Corporation
International Business Machines Corporation
Johnson & Johnson
The JPB Foundation
JSM Charitable Trust
Ewing Marion Kauffman Foundation
The Susan G. Komen Breast Cancer Foundation
Daniel E. Koshland, Jr. Family Fund
The Kresge Foundation
Eli Lilly and Company
Lockheed Martin Corporation
Richard Lounsbery Foundation
Lumina Foundation for Education
Josiah Macy, Jr. Foundation
Merck Company Foundation
Microsoft Corporation
The Ambrose Monell Foundation
Monsanto Company
National Multiple Sclerosis Society
Northrop Grumman Corporation
Northrop Grumman Foundation
Novartis Pharmaceuticals Corporation
Nuclear Threat Initiative
O’Donnell Foundation
The David and Lucile Packard Foundation
Peter G. Peterson Foundation
Pfizer, Inc.
Robert Pritzker Family Foundation
Research Corporation for Science Advancement
Rockefeller Brothers Fund
Richard & Hinda Rosenthal Foundation
Sanofi-Aventis
Shell Oil Company
The Spencer Foundation
The Starr Foundation
The Wellcome Trust
Robert W. Woodruff Foundation
Xerox Corporation

General Aero-Science Consultants, LLC
General Electric Company
General Electric Foundation
Geosynthetic Institute
Gerstner Family Foundation
Gratis Foundation
Hewlett-Packard Company
Honeywell International Charity Matching
Hopper-Dean Foundation
Horizon Foundation for NJ Matching Gifts
New Staff and Mirzayan Fellows Join Program Office

Maggie Bartolomeo joined the staff as communications/media associate. She comes to us from WTOP Radio, where, in her capacity as news assistant, she worked at the operations desk and as assistant editor—recommending and researching stories, contacting newsmakers, editing scripts and audio, and managing daily operations of the newsroom and live broadcasting.

At the same time she was working as an editor, news correspondent, and broadcast engineer at Westwood One, researching, writing, recording, and producing pieces heard by millions of listeners across the nation. In addition, she pulled clips for breaking news stories and engineered the board for the nationally broadcast Jim Bohannon Show. She has also worked as an associate producer for The Press Pool with Julie Mason on Sirius XM’s POTUS,
Channel 124, researching and booking guests and developing a social media presence through tools such as Twitter and SoundCloud.

Maggie has been interested in radio since she began volunteering for the University of Maryland’s radio station in 2012, which she continued until her graduation there in 2015.

In her free time, Maggie says she frequently practices her news voice when she thinks no one is listening . . . spends a lot of time reading (and occasionally speaking with other people) . . . and adores Captain America and even has a life-size shield in her room.

Maggie will work to promote NAE activities and the engineering profession through both social and traditional media channels. She will be responsible for updating and enhancing the Grand Challenges for Engineering website and will help promote the Grand Challenges Scholars Program and the Global Grand Challenges Summit. Of course, she will also work on our WTOP/Federal News Radio series.

B.L. (Rama) Ramakrishna joined the NAE staff on January 23 as director of the NAE Grand Challenges Scholars Program (GCSP) Network. He is dedicated to preparing engineers who not only have the necessary engineering skills but also the cross-disciplinary knowledge, entrepreneurial spirit, global perspective, and sense of mission needed to lead our country and the world to meet the major challenges facing humankind in the 21st century. He passionately believes that science, technology, innovation, and partnership will transform global development and help address the challenges facing developing countries in particular.

Most recently he was the Diane and Gary Tooker Professor at the School of Engineering for Matter, Transport, and Energy in the Arizona State University (ASU) Fulton Schools of Engineering. He launched the ASU GCSP in 2009 and led or co-led it until 2013, when he took a Jefferson Science Fellowship at the US State Department. In 2014 he returned to ASU, where he helped establish a Humanitarian Engineering Program. From 2001 to 2011 he was director of Down to Earth Science, ASU’s NSF-sponsored Graduate STEM Fellows in K–12 Education (GK–12) Project, whose goal was to bring cutting-edge research in the physical, life, and engineering sciences to K–12 teachers and students in order to strengthen the pipeline for recruiting highly motivated and well-prepared students to STEM careers.

He is active in efforts to enhance public understanding of science and engineering and advises Arizona Science Center on its exhibits and educational programs. During his Jefferson Fellowship he served as a senior science and technology advisor in the African bureau of the USAID Office of Sustainable Development, and has been recognized with fellowships from Germany and NATO for his expertise in international collaborations.

Rama received his PhD from the Indian Institute of Technology, Madras, and joined ASU after postdoctoral work at the University of Zurich, Phillips University in Marburg, and Washington State University.

The GCSP director position was established to support the growing number of universities and engineering schools in the United States and around the world that offer the GCSP to prepare their students to contribute to solving some of the biggest challenges of our time. The activities of the director will focus on the continued growth of the GCSP Network as well as data collection, the sharing of best practices, GCSP-related research, community-building efforts, outreach, and partner development.

Albert Manero II completed his PhD in mechanical engineering at the University of Central Florida in December 2016. His dissertation focused on nondestructive characterization of aerospace ceramic composites via synchrotron radiation, conducted in part at Argonne National Laboratory and the German Aerospace Center during his Fulbright graduate research experience in Köln. He is the founder of Limbitless Solutions nonprofit, which is devoted to designing bionic arms for children in need at no cost to families. Limbitless looks to encourage students to identify technology infused with compassion as a tool to have a positive impact on their communities. Through his participation in the Mirzayan Fellowship, Albert hopes to gain experience in science policy and to explore perspectives for ways to improve STEM education for students. He’ll work on LinkEngineering and other K–12 engineering–related activities.

Amy Shaw is completing a PhD in environmental engineering at Vanderbilt University, where she also received her MS in environmental engineering and BE in civil engineering with a mathematics minor. Her graduate research focuses on reducing negative water quality impacts while optimizing hydropower dam operations.
through integration of high-fidelity simulation models in decision support tools. Before graduate school she worked on water resources projects as an intern at the engineering consulting firm CDM. For fun, she enjoys wheel-throwing ceramic pottery, rooting for the Nashville Predators and Vanderbilt Commodores, and going to concerts. She is enthusiastic about participating in science outreach and education programs. In the Mirzayan Fellowship Program, Amy seeks to hone her ability to communicate ideas with all audiences, explore policy career opportunities available to scientists and engineers, and enhance her understanding of how to turn ideas into reality. She will work on a variety of activities while here, including the Global Grand Challenges Summit, use of the Grand Challenges in K–12, and media activities such as researching story ideas and working on news releases.

### Calendar of Meetings and Events

<table>
<thead>
<tr>
<th>Date Range</th>
<th>Event Title and Details</th>
<th>Date Range</th>
<th>Event Title and Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 26–27</td>
<td>Workshop on Engagement of Engineering Societies in Undergraduate Engineering Education</td>
<td>May 11–12</td>
<td>NAE Council Meeting</td>
</tr>
<tr>
<td>March 1–31</td>
<td>Election of NAE Officers and Councillors</td>
<td>May 16</td>
<td>NAE Regional Meeting Northwestern University, Evanston, Illinois</td>
</tr>
<tr>
<td>March 31–April 2</td>
<td>German-American Frontiers of Engineering Symposium GE Aviation, Evendale, Ohio</td>
<td>May 25</td>
<td>NAE Regional Meeting Akamai Technologies, Cambridge, Massachusetts</td>
</tr>
<tr>
<td>April 1</td>
<td>NAE Awards Call for Nominations closes</td>
<td>May 30</td>
<td>Bernard M. Gordon Prize for Innovation in Engineering and Technology Education Presentation Northwestern University</td>
</tr>
<tr>
<td>April 5</td>
<td>NAE Regional Meeting Google, Mountain View, California</td>
<td>June 22–24</td>
<td>China-America Frontiers of Engineering Shanghai</td>
</tr>
<tr>
<td>April 13</td>
<td>NAE Regional Meeting Carnegie Mellon University, Pittsburgh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 19–20</td>
<td>NAE Regional Meeting Georgia Institute of Technology, Atlanta</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All meetings are held in National Academies facilities in Washington, DC, unless otherwise noted.

### In Memoriam

**VITELMO V. BERTERO**, 93, professor emeritus of civil and environmental engineering, University of California, Berkeley, died October 24, 2016. Dr. Bertero was elected to the NAE in 1999 for contributions to improvements in seismic design and the construction of steel and reinforced concrete structures.

**ERICH BLOCH**, 91, director, the Advisory Group at Huron, died November 25, 2016. Mr. Bloch was elected to the NAE in 1980 for leadership in the development of semiconductor technologies for computers.

**JOSEPH V. CHARYK**, 96, retired chair and CEO, COMSAT Corporation, died September 28, 2016. Dr. Charyk was elected to the NAE in 1973 for basic contributions relating to space flight and leadership in development of communications satellites.

**RAY CLOUGH**, 92, Nishkian Professor of Structural Engineering Emeritus, University of California, Berkeley, died October 8, 2016. Dr. Clough was elected to the NAE in 1968 for analysis, design, and applications of structures for dynamic loadings, including earthquakes.

**KEITH H. COATS**, 81, technical director, Coats Engineering Inc., died September 13, 2016. Dr. Coats was elected to the NAE in 1988 for pioneering work in the development of computer methods for simulation of oil and gas reservoir performance.

**SEYMOUR B. COHN**, 94, engineering consultant, S.B. Cohn Associates, died September 9,
2015. Dr. Cohn was elected to the NAE in 1991 for innovative accomplishments in the development of basic components in microwave engineering.

W. DALE COMPTON, 88, Lilian M. Gilbreth Distinguished Professor of Industrial Engineering Emeritus, Purdue University, died February 7, 2017. Dr. Compton was elected to the NAE in 1981 for exceptional leadership in developing advanced automotive technologies, individual achievements in engineering physics, and innovative contributions in promoting university-industry relations.

JAMES W. COOLEY, 89, retired research staff, IBM Thomas J. Watson Research Center, died June 29, 2016. Dr. Cooley was elected to the NAE in 2000 for the creation and development of the Fast Fourier Transform (FFT) algorithm for time series analysis.

L. ERIC CROSS, 93, Evan Pugh Professor Emeritus of Electrical Engineering, Pennsylvania State University, died December 29, 2016. Dr. Cross was elected to the NAE in 1983 for contributions to the development of electroceramic, dielectric, and piezoelectric materials.

MILDRED DRESSELHAUS, 86, Institute Professor of electrical engineering and physics, Massachusetts Institute of Technology, died February 20, 2017. Dr. Dresselhaus was elected to the NAE in 1974 for contributions to the experimental studies of metals and semimetals, and to education.

JAY W. FORRESTER, 98, professor emeritus of management, Massachusetts Institute of Technology, died November 16, 2016. Mr. Forrester was elected to the NAE in 1967 for design and development of magnetic core memory devices.

ROBERT N. HALL, 96, retired physicist, General Electric Company, died November 7, 2016. Dr. Hall was elected to the NAE in 1977 for contributions to alloyed junctions, p-i-n, tunnel and laser diodes, and ultrapurification of semiconductors.

CHIEH-SU HSU, 92, professor emeritus of applied mechanics, University of California, Berkeley, died July 25, 2014. Dr. Hsu was elected to the NAE in 1988 for the development of innovative techniques, especially cell-to-cell mapping, and for the analysis of the dynamics of nonlinear systems.

STEPHEN C. JACOBSEN, 75, Distinguished Professor of Mechanical Engineering, Center for Engineering Design University of Utah, and president, Raytheon Sarcos, died April 3, 2016. Dr. Jacobsen was elected to the NAE in 1990 for engineering artificial kidneys, the Utah artificial arms, robots, and micromotors and for successful commercial implementation of advanced products.

ROBERT L. JOHNSON, 96, retired corporate vice president, McDonnell Douglas Corporation, died September 4, 2016. Mr. Johnson was elected to the NAE in 1976 for pioneering design of integrated control systems and systems development of guided missiles.

NIKOLAY P. LAVEROV, 86, vice president, Russian Academy of Sciences, died November 27, 2016. Dr. Laverov was elected a foreign member of the NAE in 2005 for leadership in the uses of uranium and for the direction of national and international programs for the management of radioactive waste.

ARTUR MAGER, 97, independent consultant, died November 22, 2016. Dr. Mager was elected to the NAE in 1977 for contributions in turbulent flow aerodynamics and engineering leadership to space and missile programs.

FRANKLIN K. MOORE, 94, Joseph C. Ford Professor Emeritus of Mechanical Engineering, Cornell University, died November 21, 2016. Dr. Moore was elected to the NAE in 1984 for pioneering fundamental research in fluid mechanics and continuing innovative engineering contributions to power-plant cooling and rotating machinery efficiency.

JACQUES I. PANKOVE, 93, retired professor of electrical engineering, University of Colorado Boulder, died July 12, 2016. Dr. Pankove was elected to the NAE in 1986 for pioneering contributions to the advancement of electronic devices, including transistors and electro-optics.

PAUL S. PEERCY, 75, dean emeritus, College of Engineering, University of Wisconsin–Madison, died October 20, 2016. Dr. Peercy was elected to the NAE in 2001 for significant fundamental discoveries, important new measurement techniques, and visionary leadership in creating and managing outstanding laboratories in materials research.

WILLIAM R. PRINDLE, 90, retired division vice president and
associate director—technology, Corning Incorporated, died December 29, 2016. Dr. Prindle was elected to the NAE in 1990 for outstanding leadership and innovation in the direction of industrial research and development in modern glass and ceramics technology.

DONALD E. PROCKNOW, 93, retired vice chair, Lucent Technologies, died July 1, 2016. Mr. Procknow was elected to the NAE in 1988 for outstanding leadership of a premier telecommunications manufacturing institution through an era of technological change.

GERALD F. ROSS, 85, retired chair of the board, Geospatial Systems Inc., died October 10, 2016. Dr. Ross was elected to the NAE in 1995 for contributions to time-domain electromagnetics and in ultra-wideband radar.

MYRON TRIBUS, 94, cofounder and director, Exergy Inc., died August 31, 2016. Dr. Tribus was elected to the NAE in 1973 for contributions to applied sciences that support engineering, to engineering education, and for professional service in education, government, and industry.

GREGORY S. VASSELL, 94, consultant and retired senior vice president, System Planning, American Electric Service Power Corporation, died November 3, 2016. Mr. Vassell was elected to the NAE in 1980 for contributions in the field of electric energy supply, both as to its technical features and its societal implications.

IRWIN WELBER, 92, retired president, Sandia National Laboratories, died December 17, 2016. Dr. Welber was elected to the NAE in 1988 for major contributions to the advancement of capacity and economy in satellite, microwave radio, submarine cable, and digital transmission systems.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Academies of Sciences, Engineering, and Medicine. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street NW–Keck 360, Washington, DC 20001. For more information or to place an order, contact NAP online (www.nap.edu) or by phone (800-624-6242). Note: Prices quoted are subject to change without notice. There is a 10 percent discount for online orders when you sign up for a MyNAP account. Add $6.50 for shipping and handling for the first book and $1.50 for each additional book. Add applicable sales tax or GST if you live in CA, CT, DC, FL, MD, NC, NY, PA, VA, WI, or Canada.

**Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2016 Symposium.** This volume presents papers on the topics covered at the National Academy of Engineering's 2016 US Frontiers of Engineering Symposium. Every year the symposium brings together 100 outstanding young leaders in engineering to share their cutting-edge research and innovations in selected areas. The 2016 symposium was held September 19–21 at the Arnold and Mabel Beckman Center in Irvine, California. The intent of this book is to convey the excitement of this unique meeting and to highlight innovative developments in engineering research and technical work.

NAE member Robert D. Braun, dean of engineering and applied science, University of Colorado Boulder, chaired the symposium organizing committee. Paper, $45.00.

**The Role of Experimentation Campaigns in the Air Force Innovation Life Cycle: Proceedings of a Workshop.** A workshop was held in January 2016 to define and assess the current use of experimentation campaigns in the Air Force, evaluate barriers to their use, and make recommendations to increase their use. Participants at the workshop presented a broad range of issues, experiences, and insights related to experimentation, experimentation campaigns, and innovation. This publication summarizes the presentations and discussions from the workshop.

NAE members on the study committee were Lester L. Lyles (cochair), independent consultant, Vienna, VA; Antonio L. Elias, executive vice president and chief technical officer, Orbital ATK Inc.; and Robert A.K. Mitchell, consultant, Robert A.K. Mitchell Consulting,
and retired vice president, Northrop Grumman. Free PDF.

**The Changing Landscape of Hydrocarbon Feedstocks for Chemical Production—Implications for Catalysis: Proceedings of a Workshop.** As a result of abundant domestic supplies of affordable natural gas and natural gas liquids resulting from the dramatic rise in shale gas production, the US industry has gone from the world's highest-cost producer in 2005 to among the lowest-cost producers. There is an opportunity to discover and develop new catalysts and processes to enable the direct conversion of natural gas and natural gas liquids into value-added chemicals with a lower carbon footprint. The economic implications could be significant, as commodity, intermediate, and fine chemicals represent a higher-economic-value use of shale gas compared with its use as a fuel. Participants at a March 2016 workshop sought to better understand the opportunities for catalysis research, identify gaps in the current research portfolio, and help target the efforts of US researchers and funding agencies on areas of science and technology development most critical to achieving advances in catalysis. This publication summarizes the workshop presentations and discussions.

NAE members on the workshop planning committee were Alexis T. Bell (chair), professor, Department of Chemical and Biomolecular Engineering, University of California, Berkeley; Montgomery M. Alger, Department of Energy and Mineral Engineering, Pennsylvania State University; Maria Flytzani-Stephanopoulos, Robert and Marcy Haber Endowed Professor in Energy Sustainability, Department of Chemical and Biological Engineering, Tufts University; and James C. Stevens, retired Dow Distinguished Fellow, Core Research and Development, The Dow Chemical Company. Paper, $50.00.

**A Threat to America’s Global Vigilance, Reach, and Power—High-Speed, Maneuvering Weapons: Unclassified Summary.** The National Academies of Sciences, Engineering, and Medicine was asked by the Assistant Secretary of the Air Force for Science, Technology, and Engineering to assess the threat of high-speed weapons and provide recommendations to counter the threat. This report reviews current and evolving threats and current and planned US efforts and capabilities to counter them; identifies current gaps and opportunities for the United States Air Force (USAF) to significantly contribute to US efforts to counter high-speed threats; and recommends actions for the USAF in materiel, nonmateriel, and technology development to address the identified opportunities and gaps.

NAE members on the study committee were Malcolm R. O’Neill, former Assistant Secretary of the Army, Acquisition, Logistics and Technology, retired vice president and CTO, Lockheed Martin Corporation, and retired Lieutenant General, US Army; and David A. Whelan, vice president, engineering, Boeing Defense, Space and Security, The Boeing Company. Free PDF.

**SBIR/STTR at the Department of Energy.** The Small Business Innovation Research (SBIR) program, one of the largest examples of US public-private partnerships, was established in 1982 to encourage small businesses to develop new processes and products and to provide quality research in support of US government missions. The Small Business Technology Transfer (STTR) program was created in 1992 to expand joint venture opportunities for small businesses and nonprofit research institutions by requiring small business recipients to collaborate formally with a research institution. Congress tasked the National Research Council with (1) undertaking a comprehensive study of how the SBIR and STTR programs have stimulated technological innovation and used small businesses to meet federal R&D needs and (2) recommending improvements to the programs. The study’s first round (2004–2009) resulted in reports on the programs at the five agencies responsible for 96 percent of the programs’ operations, including the Department of Energy (DOE). This second round presents a second review of the DOE SBIR program operations. The report notes that, although a defining feature of the US economy is a high level of entrepreneurial activity, converting discoveries in important, dynamic areas such as genomics, bioinformatics, and nanotechnology into innovations for the market involves substantial challenges. The US capacity for innovation can be strengthened by addressing these challenges.

NAE members on the study committee were Jacques S. Gansler (chair), chair and CEO, ARGIS Group; Charles E. Kolb, president and CEO, Aerodyne Research Inc.; and Duncan T. Moore, vice provost for entrepreneurship and Rudolf and Hilda Kingslake Professor of Optical Engineering, University of Rochester. Paper, $70.00.
An Assessment of the National Institute of Standards and Technology Center for Nanoscale Science and Technology: Fiscal Year 2016. At the request of the National Institute of Standards and Technology (NIST), the National Academies of Sciences, Engineering, and Medicine has, since 1959, annually assembled panels of experts from academia, industry, medicine, and other scientific and engineering communities to assess the quality and effectiveness of the NIST measurements and standards laboratories, of which there are now seven, as well as the adequacy of the laboratories’ resources. This report assesses the scientific and technical work performed by the NIST Center for Nanoscale Science and Technology and identifies accomplishments, challenges, and opportunities for improvement.

NAE members on the study panel were Kanti Jain (chair), professor, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign; James J. Coleman, Erik Jonsson School of Engineering and Computer Science Distinguished Chair, Department of Electrical Engineering, University of Texas at Dallas; Elsa Reichmanis, professor, Department of Chemical and Biomolecular Engineering, Georgia Institute of Technology; Kenneth L. Reifsnider, Presidential Distinguished Professor of Mechanical and Aerospace Engineering and director, Institute for Predictive Methodology, University of Texas at Arlington Research Institute; and Anil V. Virkar, professor and chair, Department of Materials Science and Engineering, University of Utah. Free PDF.

A 21st Century Cyber-Physical Systems Education. Cyber-physical systems (CPS) are “engineered systems that are built from, and depend on, the seamless integration of computational algorithms and physical components.” With the development of low-cost sensing, powerful embedded system hardware, and widely deployed communication networks, reliance on CPS for system functionality has dramatically increased. However, engineers responsible for developing CPS but lacking the appropriate education or training may not fully understand (1) the technical issues associated with CPS software and hardware or (2) techniques for physical system modeling, energy and power, actuation, signal processing, and control. Moreover, they may be designing and implementing life-critical systems without appropriate training in CPS methods needed for verification and to ensure safety, reliability, and security. This report examines the intellectual content of the emerging field of CPS and its implications for engineering and computer science education. It is intended to inform those who might support efforts to develop curricula and materials, faculty and university administrators, industries with needs for CPS workers, and current and potential students about intellectual foundations, workforce requirements, employment opportunities, and curricular needs.

NAE members on the study committee were Panganamala R. Kumar, College of Engineering Chair in Computer Engineering, Texas A&M University–College Station; Sanjoy K. Mitter, professor of electrical engineering, Massachusetts Institute of Technology; and José M.F. Moura, Philip and Marsha Dowd University Professor, Department of Electrical and Computer Engineering, Carnegie Mellon University. Paper, $50.00.

The Role of Science, Technology, Innovation, and Partnerships in the Future of USAID. The US Agency for International Development (USAID) plays a vital role in promoting US national and international interests by advancing strategies for using science, technology, and innovation (STI) to respond to global challenges. The agency depends on the engagement of science institutions and other innovative enterprises and their commitment to work in partnership with USAID to research, test, and scale solutions. This report provides an assessment and advice on the current and future role for STI in USAID assistance programs and on the role of partnerships in the public and private sectors to expand impact. The report examines challenges and opportunities for USAID in expanding the use of STI in development assistance; assesses how USAID has deployed STI; and recommends priority areas for improvement in partnership with others.

NAE member Rebecca R. Richards-Kortum, Malcolm Gillis University Professor, Department of Bioengineering, Rice University, was a member of the study committee. Paper, $58.00.