Summer 2011

CHANGING THE CONVERSATION ABOUT ENGINEERING

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

Promoting the technological welfare of the nation by marshalling the knowledge and insights of eminent members of the engineering profession.

The
BRIDGE

NATIONAL ACADEMY OF ENGINEERING

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Editor's Note

Ellen Kullman

Changing the Conversation

A major topic of conversation in the nation's capitol, and the nation's living rooms, is how well the United States will compete in the global marketplace of the future. The answer will depend largely on how well we, as parents, business leaders, teachers, and politicians, prepare our children and whether we can rally around education to give our young people the solid foundation they will need to build their future and ours.

I am proud to be co-chair, with my colleague **Chuck Vest**, of a new phase of the NAE initiative called Changing the Conversation. The goal of this program, funded by the National Science Foundation (NSF), is to excite and inspire young people to go into engineering-related careers.

We want to interest students in who engineers are and what they do, to ignite a spark of invention and innovation, creativity and imagination to open young minds to the possibilities of becoming engineers. Students need to understand how engineers make a difference in their neighborhoods, communities, and the world by solving problems using science and technology, and that they, too, can join in those efforts. From safer drinking water to new medical devices, from electric cars to the grandest skyscrapers and bridges, engineers use their knowledge of science and technology to improve people's lives in meaningful ways.

This issue of *The Bridge* is devoted to improving the way we tell our stories and engage and mentor young people so they "get it" and can take on the challenges of making a difference as engineers of the future.

In the first article, Chuck Vest begins by exhorting us, all of us, from politicians to business people, to move beyond our current situation and short-term problems toward solutions of the long-term challenges facing our nation and our planet. In *The Image Problem for Engineering: An Overview*, he addresses a variety of issues that are keeping us from working toward the goals of a well-educated, globally competitive workforce and a country with a vibrant economy and a healthy population with a continuing high quality of life.

Mitch Baranowski is founding partner and chief creative officer of BBMG, a marketing research firm in New York. As the grandson of a cattle rancher in Texas, he knows the literal meaning of "branding." In his article, he explains how branding as a marketing tool can help establish a product, a company, or even a movement in the eyes of the consumer. *Rebranding Engineering: Challenges and Opportunities* focuses on the five laws of branding and how, in our new campaign, we can reshape public perceptions of our profession, shake off our outdated legacies, and rebrand engineering from the inside out. As he says, it's all about delivering on a promise—and that's exactly what we have to do—deliver.

Maria Ivancin, a professor in the School of Communication at American University, puts her everyday experience to work and walks us through the steps of building a coordinated outreach campaign, to reach today's young people. In *Framework for a Coordinated Outreach Campaign*, she explains the architecture of a successful campaign from the ground up and the importance of image building, brand identity, and workforce recruitment that can put us on the road from research to action.

Reaching out to recruit students in new ways is the focus of Janet Yowell and Jackie Sullivan's case study on *Who Should Become an Engineer?* With few students, teachers, or members of the general public able to describe what engineers do, the need to improve education and identify and nurture students with the desire and talent to study math and science is at an all-time high. The authors describe how consistent messages and recruiting materials are being used at the University of Colorado Boulder to convey how engineers help people and communities and that engineering can be a fulfilling, exciting career choice for young people. The heart of their message is that engineering is a helping profession that "shapes the health and welfare of people everywhere, as well as the health and welfare of our planet."

Marisa Wolsky, executive producer at the WGBH Educational Foundation, describes *Engineering a Change in Perception*. Her article chronicles how WGBH has developed messages that promote positive images of engineering and how they have succeeded in delivering those messages and engaging young people in innovative ways by using multimedia outlets. The two projects she describes, *Engineer Your Life* (EYL) and *Design Squad*, have had a significant impact on the learning and understanding of science and engineering principles for girls and boys from a wide range of backgrounds.

Few professions turn as many ideas into realities as engineering. Few have as direct and positive an effect on people's everyday lives. We are counting on engineers to help us meet the needs of the 21st century. We hope this issue introduces our readers to new ideas and suggestions for action that can change the conversation about engineering—for good.

Ellen Kullman, co-chair
Committee on Implementing Engineering Messages

In Remembrance of George Bugliarello

I had the privilege of working with George Bugliarello on *The Bridge* for 11 years. As a labor of love, George had assumed the voluntary position of "interim" editor in chief in 1997, three years before I arrived on the scene, and he continued to watch over our progress until the very last days of his life. He completed an "Editor's Note" for the March 2011 issue on urban sustainability a few days before he went into the hospital and was working on a full length article for the same issue when his strength ran out.

In recent years, George was involved mostly in planning issues, recruiting writers, and resolving emergencies. He kept in touch through his devoted assistant, Rose Emma, who relayed our messages to and from wherever he happened to be. When he was in Washington, he always found time to stop in at the office.

George wore his brilliance and his accolades lightly. He had an air of politesse and humility and a sense of humor that drew people to him and inspired respect. This gentle man also had the skills of a diplomat when it came to soothing bruised egos or enticing a friend or acquaintance to take on one more task and write for us.

I will greatly miss George's enthusiasm and support, and I feel honored to have worked with him. But mostly I am proud to have called him my friend.

Carol R. Arenberg
Managing Editor

To reach our strategic goals, we must have a well educated, globally competitive workforce.

The Image Problem for Engineering

An Overview

Charles M. Vest is president, National Academy of Engineering, and co-chair, Committee on Implementing Engineering Messages.

Charles M. Vest

This is an age in which we are fixated on near-term issues, especially in the political domain, where immediate goals crowd out strategic goals. It has become a truism that members of Congress are in perpetual campaign mode and therefore nearly unable to make a public statement, let alone attend to public policy, without keeping at least one eye focused on the polls and making a mental calculation of voter appeal.

Our free-market system, despite its remarkable benefits, is also driven beyond reason by the impact of quarterly earnings. Indeed, a recent poll showed that 80 percent of chief financial officers of U.S. firms indicated they would be willing to cut R&D to meet the next quarter's profit projections (Graham et al., 2005). Unhappily, all of these factors tend to make three months the natural business time scale and two years or less the natural political time scale.

This is unfortunate for both our nation and the world, because we are facing some very important long-term, strategic issues. The larger forces of macroeconomics and the global economy are driven by factors beyond quarterly reports to Wall Street, and achieving global health as the world population climbs toward nine billion will take time.

Mother Nature does not turn on a dime. She goes about her business without worrying about the next election. Her eruptions do not occur on cue, and her responses to human impacts build over decades. War and terrorism are also responses that build over decades or even centuries. We seem to have forgotten that a life well lived is not dedicated to the thrill of the moment, but to human progress and to leaving a positive legacy for our children and beyond.

The only way to move beyond the immediate and toward the strategic is to focus on widely shared goals. Surely, as citizens of this nation, we have a shared "Mega Goal" of creating and sustaining a nation with a vibrant economy, good health, security, and a good quality of life. Indeed, this is the goal, "health, prosperity, and security as a nation in the modern world," set forth explicitly in 1945 by Vannevar Bush in his seminal report, *Science the Endless Frontier*. Since then, his report has been the touchstone of science and technology policy in the United States.

The National Academies 2007 report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (NAS/NAE/IOM, 2007) is a recent example that follows in this tradition. The report was written in response to a bipartisan congressional request to identify key actions the federal government should take to "enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the 21st century."

I hope we can begin with the assumption that all stakeholders support the Mega Goal of creating and sustaining a nation with a vibrant economy, good health, security, and a good quality of life. Next, we must identify the key stakeholders: the American public, young people, and policy makers, as well as industry and academia. Broadly speaking, leaders of industry and universities believe, as do we in the National Academy of Engineering, that to attain the Mega Goal we must have a well educated, globally competitive workforce. In particular, we must increase the quantity and diversity, and improve the quality of our engineering workforce.

Improving and Expanding the Engineering Workforce

Most of our larger companies, which are crucial for advancing and deploying technology-based products and services, face a substantial wave of retiring engineers. Perhaps even more critical is the continuing need for a new generation of bright engineers, who, like their predecessors, become innovators and entrepreneurs who push the cutting edge of technology, develop new products and services, and create and fuel the enterprises of the 21st century. Indeed, Silicon Valley venture capitalist Floyd Kwamme has defined his profession as "the search for good engineers."

The need for young engineers is apparent when we compare the number of graduating engineers in the United States with the numbers in other nations and regions (Figure 1). Across Asia, 21 percent of university graduates earn engineering degrees. In Europe, the number is about 12.5 percent. The equivalent percentage of U.S. university graduates who earn engineering degrees is just 4.5 percent.

But this situation wasn't created yesterday. It's been going on for quite a while. So you might ask how U.S. industry has remained technologically successful. The answer is, in large part, that we have imported a substantial portion of our engineering talent from other countries. The openness of our nation, our companies, and our universities to talented engineers from around

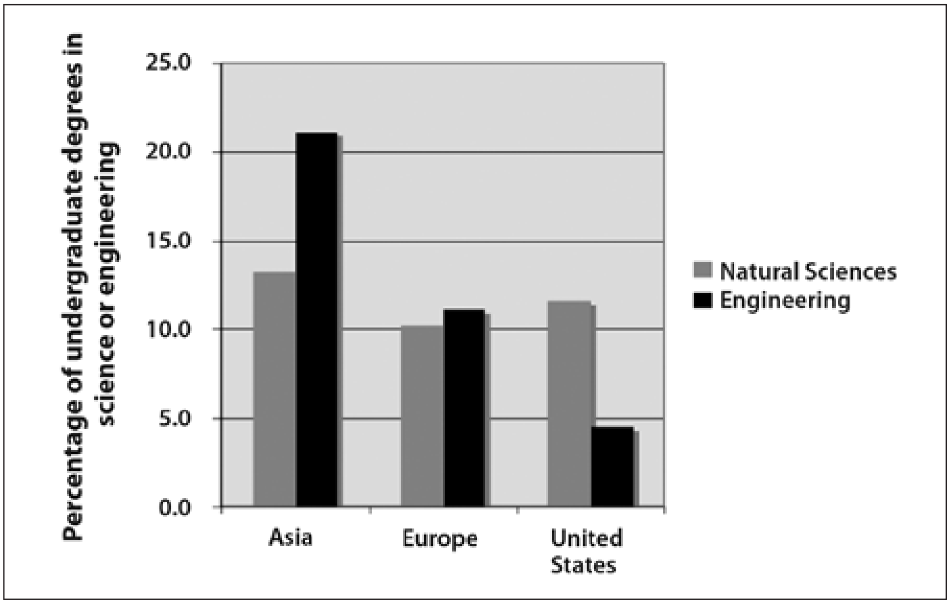

FIGURE 1 Percentage of undergraduate degrees in the natural sciences and engineering in Asia, Europe, and the United States (for 2006 or the most recent year). Source: NSF, 2010a.

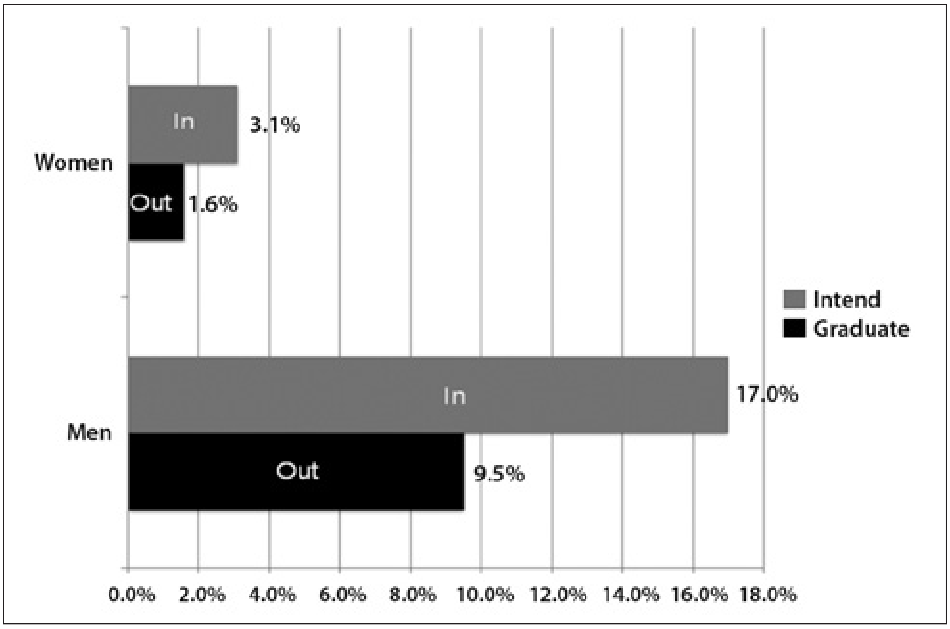

FIGURE 2 Comparison of the percentages of students who intend to major in engineering and the percentages of engineering bachelor degrees awarded in the United States in 2007. Light gray = percentage of entering freshmen who intend to major in engineering. Black = percentage of graduates with bachelor's level engineering degrees. Sources: DOEd, 2008; NSF, 2010b.

the world has traditionally been a source of strength and pride.

In fact, openness is the bedrock of our national strength. But today, it is also a vulnerability, because opportunities for rapid, professional growth are opening up in many other countries, prompting foreign-born engineers to return home after graduation rather than pursuing professional careers in this country. And, to be frank, the implementation of immigration policy and processes, and the world's perception of openness in the United States, have suffered greatly since September 11, 2001.

Add to this that our public primary and secondary school systems are failing many of our youngsters, who, as a result, are sinking below global standards in STEM education, and we have a very big problem. The engineering workforce issue is also greatly exacerbated by the fact that more than 50 percent of students who enter universities with the intention of majoring in engineering leave the discipline before graduation (Figure 2). Thus a major, and painfully obvious part of the solution to our engineering workforce problem is making engineering education more inspiring and engaging.

Increasing Diversity

Increasing the diversity of our engineering workforce is also essential to achieving our Mega Goal. In the American engineering community, diversity generally connotes the inclusion and leadership of more women and underrepresented minorities. For many decades, the drive to increase diversity has been motivated by a desire to correct historical inequities and to be more fair and just. In 21st century America, these historical and ethical motivations remain strong.

However, we can no longer delay facing the diversity issue. Continuing underrepresentation and underutilization of ethnic minority groups is no longer an option. Our population is changing rapidly, and minorities, who constitute its most rapidly growing segment, now account for almost 30 percent of the population. Nevertheless, they comprise only 9.1 percent of Americans working in science and engineering occupations (NAS/NAE/IOM, 2011).

Despite their large numbers, only about 5 percent of our recent engineering graduates are African American, and approximately 7.5 percent are Hispanic (Figure 3). If these small percentages persist as these ethnic groups become larger and larger fractions of our population, the number of U.S. engineers will inexorably plummet.

Achieving Gender Balance

Gender balance has been attained much more rapidly in other professions than in engineering. In fact, only 1.6 percent of recent female graduates of U.S. universities are engineers. The percentage of women in the engineering workforce increased from 8.31 percent in 1995 (NSF, SESTAT, 1995) to 11.54 percent in 2006 (NSF, 2006). However, the fraction of young women pursuing engineering degrees has declined slightly since then.

Contrast this with the legal profession, where the percentage of women in the younger workforce increased from 38.99 percent in 1993 to 45.41 percent in 2010 (NALP, 2010). In health professions (dentists,

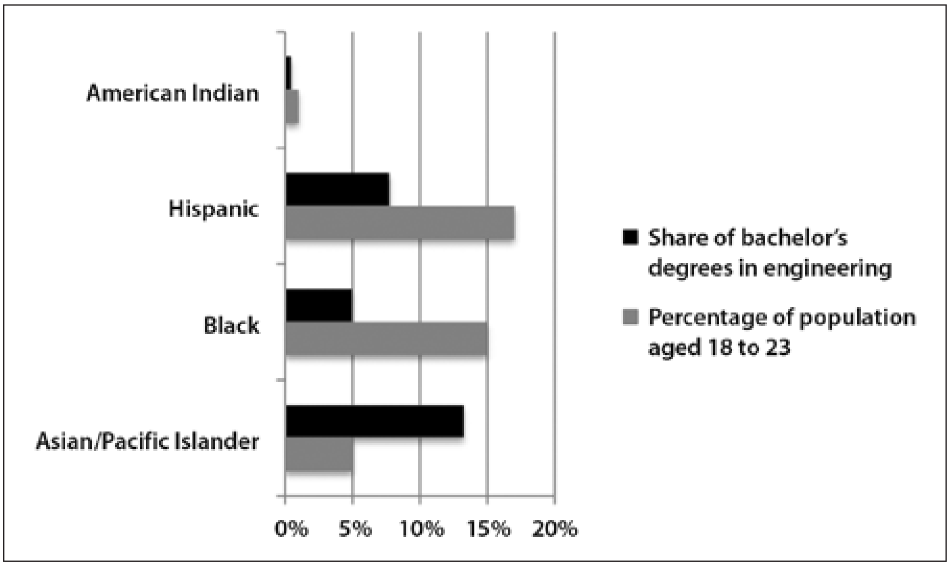

FIGURE 3 Comparison of the percentages of total bachelors degrees in engineering earned by American Indians, Hispanics, blacks, and Asian/Pacific Islanders. Sources: NSF, 2010c; U.S. Census Bureau, 1999.

medical assistants, nurses, pharmacists, and physicians) women accounted for 74.72 percent worldwide in 2000 (WHO, 2008).

Diversity and Quality

Finally, the diversity and quantity of the engineering workforce are directly related to its quality. Research clearly shows that in industry and other organizational settings, teams of individuals from diverse backgrounds consistently arrive at better solutions to problems and challenges than homogeneous teams (e.g., Page, 2007).

Changing the Conversation

So what must we change to increase the quantity, quality, and diversity of the U.S. engineering workforce, a necessary condition to meeting our Mega Goal. Above all, we have to inspire young people to take an interest in science and engineering and educate them about the opportunities engineering holds for them.

Because young people take their cues from parents, teachers, guidance counselors, and the perceptions of the general public, we must also change the public attitude toward engineering and, just as important, ensure that federal and state policy makers have a better-informed perspective on the role and importance of the national engineering enterprise. In short, all stakeholders in reaching the Mega Goal must understand the centrality of engineering to meeting our country's 21st century goals.

Determining Perceptions

To appreciate the perception issues we face with the American public, the committee that authored the 2008 NAE report, *Changing the Conversation: Messages for Improving Public Understanding of Engineering*, first investigated available polls and studies. They found, for example, that the general public perceives that engineers, more than scientists, create economic growth, strengthen national security, and make strong leaders. However, they also believe that, compared with scientists, engineers do less to save lives, are more insensitive to social concerns, and do not care as much about their communities (Table 1).

The data mirror the negative view of engineering held by many incoming college freshmen. When well-prepared first-year university students are asked why they do *not* choose to study engineering, the nearly inevitable reply is that they prefer to enter a discipline that will empower them to help others and make the world a better place. Unfortunately, this shows that engineering as a profession has done a poor job of communicating what engineers really do, why what they do is important, and why engineering is essential to facing the grand, global challenges of our times.

To supplement the Harris data and other prior efforts to understand public perceptions of engineering, the committee then commissioned a team of marketing professionals to conduct additional research. Led by the firm BBMG (one of whose principals, Mitch Baranowski, has contributed an article in this issue, p. 11), the team conducted focus groups with pre-teens, with teenagers, and with parents of teens.

This qualitative research showed, among other things, that young children have a very narrow view of the engineering profession, equating engineers with people who work on "engines." Older students had a broader view of what engineers might do. They also knew that engineers must be good at math and science. However, many of them felt that they themselves were not intelligent enough to become engineers.

TABLE 1 Perceived Characteristics of Engineers and Scientists

	Engineers	Scientists	Neither	Don't Know	Decline to Answer
Create economic growth					
2003	69%	25%	2%	3%	–
1998	51%	25%	–	5%	1%
Preserve national security					
2003	59%	29%	5%	6%	1%
1998	36%	22%	–	9%	2%
Would make strong leaders					
2003	56%	32%	6%	5%	–
1998	47%	28%	–	8%	3%
Save lives					
2003	14%	82%	1%	2%	–
1998	6%	65%	–	3%	21%
Are sensitive to societal concerns					
2003	28%	61%	5%	5%	*
1998	47%	57%	–	8%	3%
Care about their communities					
2003	37%	51%	5%	6%	1%
1998	24%	46%	–	9%	12%

Source: NAE, 2008. Source: Adapted from Harris Interactive, 2004.

Most parents perceived engineers as smart problem solvers and thought that engineering would be a good career for their child. But they also perceived engineers to be narrowly focused on technical details rather then engaged with the social and human dimensions of engineering projects.

These findings were troubling but not at all surprising. Mostly they confirmed what the committee already suspected: the core of the problem is, at least in part, communication and image.

The Positioning Statement

Despite the best intentions of the engineering community, years of effort to create an accurate, compelling image of engineering have fallen far short of that goal. The committee's challenge was to develop a more powerful messaging platform for engineering and to convince the engineering community at large to adopt it.

Following advice from BBMG, and taking into account its research, the committee crafted a positioning statement (Box 1) that defines how we believe engineering should be perceived and provides core messages to be delivered in every medium. The positioning statement also answers a number of key questions, such as what engineers do, who they serve, what makes engineering different from other professions, and what benefits engineering (and engineers) provide to society.

The positioning statement is not intended to be shared verbatim with external audiences. It is much too long and clunky for that purpose. It is meant to

BOX 1
New Positioning Statement for Engineering

No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people's everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21st century.

guide the engineering profession's decisions about how to deliver our core message.

Developing and Testing Messages

BBMG and the committee used the positioning statement to develop a number of succinct messages (Box 2) that might serve as our public face. They then rigorously tested the appeal, believability, and relevance of the messages among several thousand teens and adults through an online survey. To provide sufficient statistical power for groups currently underrepresented in engineering, the research cohort included large oversamples of African Americans and Hispanics.

BOX 2
Messages Tested in the Online Survey

- Engineers make a world of difference.
- Engineers are creative problem solvers.
- Engineers help shape the future.
- Engineering is essential to our health, happiness, and safety.
- Engineers connect science to the real world.

The testing yielded two salient findings. First, the message that invoked science to illustrate the value of engineering was the least appealing. The committee felt this showed how strongly perceptions of science (and mathematics) have shaped current perceptions of engineering.

To put this another way, messages linking skills in science and mathematics to success in engineering have clearly reached a wide audience. Although this message is correct, the research suggests that emphasizing this connection has not improved the appeal of engineering. Therefore, the committee recommended that this particular message not be used.

Second, there were significant differences between the reactions of girls and boys to the messages and in their general perceptions of engineering. For example, boys appear to have a more positive opinion of engineering as a career choice and are more likely to believe it has a positive effect on people's lives. Girls found all of the tested messages less appealing than boys did.

The research found almost no statistically significant differences among the responses of white, African American, and Hispanic participants in the survey. But the committee noted that this does not necessarily mean that messages should not be optimized for targeted populations by taking into account ethnicity, culture, language, and other factors.

Progress toward Change

In the almost three years since the report was published, the notion that the engineering community needs to change its messaging has gained some currency. A number of engineering schools, including Purdue and the University of Colorado Boulder (featured as a case study in this issue, p. 23), have adopted the new messaging platform. The report and its recommendations have also been featured at meetings sponsored by the American Society for Engineering Education, the American Association of Engineering Societies, and a variety of other groups and organizations. In addition, the National Engineers Week Foundation will include a messaging-training component in its 2012 E-Week events.

These positive responses to the report are encouraging, but we are far from reaching the critical mass of implementation necessary to make a lasting impact on public attitudes about engineering. Therefore, NAE recently secured support from the National Science Foundation to conduct a follow-on project. Co-chaired by Ellen Kullman, CEO of E.I. duPont de Nemours and Company, and me, the goals of the project, which began last year, are to provide useful and direct assistance to the engineering community via an online messaging "toolkit."

Our hope is that the Changing the Conversation website (*www.engineeringmessages.org*), launched in mid-January, will catalyze the growth of a vital community of messaging practitioners in industry, academia, government, and the nonprofit sector. The success of this campaign will depend on the participation of the very individuals and groups who have a stake in the future of engineering and of the nation's innovation engine.

Conclusion

Ensuring a vibrant engineering workforce is a necessary but not sufficient condition for ensuring a prosperous future for our nation. It is part of a mix of factors, including investments in research, promotion of innovation capacity, and improvements in K–12 STEM education, that require our attention and support. We know that improved messaging about engineering will not, by itself, reverse the disturbing trends noted in the opening section of this article.

We also know that a world-class engineering workforce is critical to our country's future prosperity and success. We believe that a concerted, rigorous effort to improve messaging and carry out a broad scale, sustained campaign over a long period of time can significantly help in the development of a high-quality, diverse engineering workforce.

The NAE committee working on this project intends to call on colleagues in business, academia, and professional societies to use these messages and their derivatives consistently and persistently to help change the focus from short-term political and financial goals to the strategic needs of our nation.

References

DOEd (U.S. Department of Education). Digest of Education Statistics 2008. National Center for Education Statistics, Institute of Education Sciences. NCES 2009-020. Available online at *http://nces.ed.gov/pubs2009/2009020.pdf*. (accessed May 4, 2011)

Graham, J.R., C.R. Harvey, and S. Rajgopal. 2005. The Economic Implications of Corporate Financial Reporting. Available online at *http://faculty.fuqua.duke.edu/~charvey/Research/Working_Papers/W73_The_economic_implications.pdf*.

NAE (National Academy of Engineering). 2008. Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington, D.C.: National Academies Press.

NALP (National Association of Legal Professionals). 2010. Women and Minorities in the Legal Profession. Available online at: *www.nalp.org/uploads/PressReleases/10NALPWomenMinoritiesPressRel.pdf*.

NAS/NAE/IOM (National Academy of Sciences/NAE/Institute of Medicine). 2007. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D.C.: National Academies Press.

NAS/NAE/IOM. 2011. Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads. Washington, D.C.: National Academies Press.

NSF (National Science Foundation). 2006. Women, Minorities, and Persons with Disabilities in Science and Engineering. Table 9-5 Employed scientists and engineers, by occupation, highest degree level, and sex: 2006. Available online at: *http://www.nsf.gov/statistics/wmpd/sex.cfm*.

NSF. 2010a. Science and Engineering Indicators. Appendix Table 2-35 First university degrees, by selected region and country/economy: 2006 or most recent year. Available online at *http://www.nsf.gov/statistics/seind10/append/c2/at02-35.xls*. (accessed May 4, 2011)

NSF. 2010b. Science and Engineering Indicators. Appendix Table 2-12 Earned bachelor's degrees, by sex and field: 1993–2007. Available at *http://www.nsf.gov/statistics/seind10/append/c2/at02-12.xls*. (accessed May 4, 2011)

NSF. 2010c. Science and Engineering Indicators. Appendix Table 2-13 Earned bachelor's degrees, by citizenship, field, and race/ethnicity: 1995–2007. Available at *http://www.nsf.gov/statistics/seind10/append/c2/at02-13.xls*. (accessed May 4, 2011)

NSF, SESTAT (National Science Foundation/Scientists and Engineers Statistical Data System). 1995. Characteristics of Scientists and Engineers in the U.S.: 1995. Table B-2 U.S. scientists and engineers, by level and field of highest degree attained, sex, and employment status: 1995. Available online at: *http://www.nsf.gov/statistics/us-workforce/1995/tables/tbB02.pdf*.

Page, S.E. 2007. The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies. Princeton, N.J.: Princeton University Press.

U.S. Census Bureau. 1999. The 18–23 Year Old Population. Slide 5: Population aged 18–23, by race: United States. Available online at *http://www.census.gov/mso/www/pres_lib/1999pop18/800x600/slide5.html*. (accessed May 4, 2011)

WHO (World Health Organization). 2000. Global Atlas of the Health Workforce. Available online at: *http://apps.who.int/globalatlas/docs/HRH/HTML/SASA_Aug08.htm* and *http://apps.who.int/globalatlas/docs/HRH/HTML/Sex_ctry.htm*.

The engineering profession hopes to reshape public perceptions by emphasizing its creative aspects and its world-improving impact.

Rebranding Engineering
Challenges and Opportunities

Mitch Baranowski is founding partner and chief creative officer of BBMG in New York.

Mitch Baranowski

I grew up in Texas, the grandson of a cattle rancher. So I was raised with a notion of branding in its purest form—a mark of ownership. The scar of a brand makes clear for all to see that this cow belongs to The Pitchfork Ranch, or that stallion to The King Ranch.

An important feature of a brand is its uniqueness. The Circle-J brand can be easily distinguished from the Lazy-5, and woe to the rustler who gets caught using a "running iron" to change one brand into another.

Today, outside of the cattle industry, branding is mostly associated with the marketing of products. In this context, a brand is less about ownership than it is about a promise—what a company stands for in the mind of the customer. The promise of a brand is conveyed not only by visual images and messages but also by experience: in the store, on a test drive, during actual usage. Strong brands deliver on their promises.

Contemporary marketing practice and theory support branding that goes beyond the traditional idea of a product. Entire industries—such as the dairy industry with its very successful *Got Milk?* campaign (Manning, 2006)—have adopted the branding concept to remake their public image. Public health causes have also used marketing to create brand awareness. First Lady Michele Obama's *Let's Move* initiative (*www.letsmove.gov*), which encourages physical activity among children, is an example of this.

Branding has also been applied to professions. Nursing, the actuarial field, and accounting have all tried to remake their images with branding campaigns. The engineering profession, through the Changing the Conversation Initiative, has embarked on a campaign to reposition itself using messages that emphasize its creative side and world-improving impact.

In this article, I describe the conceptual underpinnings of branding and branding-related challenges and opportunities that may arise as the engineering community attempts to reshape public perceptions.

Five Laws of Branding

Various rules of effective branding have been proposed by marketing experts. I suggest these can be boiled down to five simple "laws."

- Law of the Word. Great brands own one word in the minds of their customers or stakeholders. They have a little piece of our mental real estate. If I suggest the category cars and the quality of safety, most of us will think of Volvo. That is the power of branding working its insidious magic. Which word does engineering own? Which word does it want to own?
- Law of Focus. The power of a brand is inversely proportional to its scope. Most of us have never heard of a store called Children's Supermart. Established in the late 1940s, Children's Supermart sold apparel, toys and games, and diapers, but the company was not very profitable. In 1957, rebranded as Toys "R" Us, the company quickly captured 20 percent market share. Today, Toys "R" Us is the largest toy retailer in the United States. For engineering, the question is: What one thing sets engineering apart from other professions? We have a clue to the answer in the positioning statement from the *Changing the Conversation* report (NAE, 2008):

  > No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive impact on people's everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21st century.

- Law of Leadership. Companies know that leadership is an important motivator of consumer behavior. People like to associate with leading brands. Budweiser is called the "king of beers" for a reason. If the marketplace is crowded, as it is for alcoholic beverages, advertisers create a category in which they can claim leadership. Thus Heineken is the leading imported brew. Sam Adams is the leading microbrew. And Corona is the leading Mexican beer. Does engineering have a leadership position among professions? Does it need one?
- Law of Authenticity. Consumers tend to disbelieve generic claims, and they are quick to note a claim that does not match reality. Authenticity is the proof behind a brand's promise. Does your brand truly reflect who you are and what you do? Take Google, which markets itself largely as an innovation company. Employees are encouraged to spend 20 percent of their time creating new products or enhancements for existing ones. That is how we got Gmail. The law of authenticity may be the most important law in this age of social media, and it presents special challenges for engineering.

The law of authenticity—the most important law in our age of social media—presents special challenges for engineering.

- Law of Consistency. A brand must stand for something clear and consistent over time. Trends come and go, but brands should stay the same. A brand only achieves the equity level of a Nike or Apple or BP if the same message, image, and experience are ascribed consistently to the brand over time. Engineering has been remarkably consistent over many years in conveying the message that interest and achievement in mathematics and science are essential to success. The Changing the Conversation project suggests a shift to a new paradigm.

Extending the Five Laws

I now want to consider some extensions of these five laws that are particularly relevant to engineering.

Brands as Strategic Drivers

Brands should be strategic drivers. That is why organizations invest in building a brand. A brand is not about a pretty logo and a tagline. An example in the commercial sector is GE's ecoimagination™ initiative (*http://www.ecomagination.com/*). Revenues from this brand have dramatically outpaced expectations and helped drive an increase in R&D at the company (GE, 2011).

Audiences as Co-owners

It may seem counterintuitive, but your brand is not really what you say it is. Today, in the age of Twitter and Facebook, brands are co-owned with their audiences. A good illustration of this was the advertising campaign for the painkiller Motrin, which targeted "baby-wearing moms." With the tagline, "We feel your pain," it caused a firestorm online with women who took offense at this portrayal of the primary caregiver and the implication that child care is painful.[1] Essentially, the company made the mistake of defining the benefit of the brand in terms that were not relevant to the target audience. Taking down the campaign and addressing the crisis cost the company millions of dollars.

A key component for engineering is the cultivation of brand ambassadors, individuals who will represent a brand to the target audiences.

Closing the Strategic–Creative Gap

The messaging research conducted by the National Academy of Engineering (NAE) and published in *Changing the Conversation* provides a factual basis for efforts to re-brand engineering. But humans are emotional creatures who don't necessarily respond to facts. We respond to stories. We respond to seeing people like us in situations we want to be in. We are aspirational, and this must be taken into account in creative communications.

The best brands close the gap between the strategic and the creative, between the rational and irrational. A good illustration of this idea is Sloan Kettering's campaign touting the quality of its cancer care with the tagline: "Where you are treated first can make all the difference." In print ads, the story is told visually with a mother holding a handwritten note that peeks out from behind a young girl sitting in her lap. The note says, "Cancer, you said I'd never bear children. My daughter says you are wrong."

Brand Unity

Brands need to work across all media types. From a design perspective, this means brand unity, consistency, developing and following brand guidelines, and internally monitoring how well the guidelines are followed. The Product Red campaign, which raises money for the global HIV/AIDS crisis by selling numerous licensed, co-branded products, illustrates how this can be done effectively without compromising creativity (*http://www.joinred.com/aboutred*).

Building from the Inside Out

The best brands are built from the inside out. In other words, the brand must be sold internally before it can be effectively sold externally. A key component relevant to engineering is the cultivation of brand ambassadors, individuals who will represent a brand to the target audiences. An example is Intel's "Sponsors of Tomorrow" campaign (*http://www.intel.com/pressroom/archive/releases/2009/20090506corp.htm*), which visually contrasts the company's scientists and engineers with leather-clad musicians using the tagline, "Our rock stars are not like your rock stars."

Challenges for Engineering

Creating a successful brand is difficult and expensive, and it takes time. Branding for engineering faces some special challenges that must be taken into account.

The Legacy Issue

I have already mentioned the issue of mathematics and science, which is thoroughly discussed in *Changing the Conversation* (NAE, 2008). Past messaging has emphasized academic skill requirements and largely ignored messages associating engineering with social benefits. Because of this legacy, we can expect a slow shift away from the "old" brand, but only with a consistent and unified spread of new messaging.

[1] See *http://www.readwriteweb.com/archives/motrin_bows_to_social_media_pr.php*.

Achieving Coordination and Consistency

In many respects, engineering is like a decentralized "industry." Engineering schools, engineering professional societies, technology-focused companies, certain museums and science centers, and even some K–12 schools and programs all have a stake in the public perception of the field. But each of these also has unique goals, capabilities, and parochial interests. This poses obvious challenges to the coordinated, consistent delivery of messages.

About 10 years ago, NAE conducted a survey of a large number of engineering-focused organizations. In a report summarizing the survey results, NAE estimated that the engineering community was spending about $400 million annually on outreach to the public (NAE, 2002). The actual total is almost certainly higher, but the larger issue is that these funds were nearly all expended in small amounts on diffuse efforts by many different types of institutions. Until the Changing the Conversation initiative, no effort was made to move the needle of public perception in a more coordinated way.

The Language Issue

Language itself can undermine brand effectiveness. The word "engineering"—how it is used and understood—presents challenges to branding. Many people, for example, do not distinguish engineering from science or technology. In addition, engineers themselves do not always agree on what engineering is let alone how to explain it to the public. Messaging can be further muddied by attempts to draw attention to a specific sub-discipline of engineering, such as mechanical, electrical, or civil engineering.

The Promise Gap

The promise gap is a challenge for all brands. For engineering, this might mean that the new messages suggested by the Changing the Conversation project may not always align well with the experiences of young people who decide to pursue engineering studies. The messages stress creativity, solving meaningful problems, and making a difference in people's lives.

But many undergraduate engineering programs, I am told, do not deliver on these messages, focusing instead solely on high-level mathematics and science. It does little good to create messages and creative communications materials if engineering cannot deliver authentically on the promise.

Opportunities for Engineering

Imagery

In the realm of imagery, I see two distinct possibilities. One might be called geek chic, exemplified by the Intel example (cited above) or the Geek Squad, Best Buy's computer repair group. In both cases, the image cleverly makes an asset out of a potential handicap and, in the process, creates pride and an identity for employees.

The second possibility, exemplified by websites such as NAE's *Engineer Your Life* (*engineeryourlife.org*), cultivates an image that high school girls will be attracted to, in this case by featuring slightly older professional women engineers as role models, interactive games, and so on.

Many undergraduate engineering programs do not deliver on messages that stress creativity and making a difference in people's lives.

Changing the Experience

Industry, engineering schools, engineering professional societies, and others in the engineering community can also change the experience of engineering. This is true both for organizations in which recruitment and retention are at issue and for organizations that engage external audiences.

Organizations can take some immediate steps to support the development of a new brand for engineering. An internal assessment of communications efforts should begin by asking the following questions:

- Revisit stakeholders: Who is most critical to your success? How do they learn about engineering? What will engage this audience?
- Audit engineering outreach materials: How might you embed or integrate the Changing the Conversation messages?
- Review the new positioning statement: How might you pick out key words or themes and build additional messages or stories around them?

- Develop talking points: How might executives and colleagues make effective use of the new messages and materials based on them?
- Focus on storytelling: Who are your messengers or ambassadors? What images are you using?

Conclusion

Despite the difficulties of developing an effective brand and the particular challenges facing engineering, I remain optimistic. The engineering community can now take advantage of new, tested messages and taglines. Combined with appropriate imagery and experience, they offer the engineering community an opportunity to change the frame of reference—to create a brand for engineering that is at once relevant, appealing, and authentic.

References

GE. 2011. Ecoimagination Fact Sheet. Available online at *http://www.ecomagination.com/about/fact-sheet/*.

Manning, J. 2006. Got milk? marketing by association. Associations Now (July). Available online at *http://www.asaecenter.org/Resources/ANowDetail.cfm?ItemNumber=18644*.

NAE (National Academy of Engineering). 2002. Raising Public Awareness of Engineering. Washington, D.C.: National Academies Press.

NAE. 2008. Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington, D.C.: National Academies Press.

Despite many challenges, the engineering community is poised to launch an effective outreach campaign.

Framework for a Coordinated Outreach Campaign

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Maria Ivancin

Joining forces for protection, to achieve a common goal, or to take advantage of an opportunity is not a new idea. Countries have formed alliances to fight common foes. Political parties have joined forces to advance an issue. In the business world, companies have recognized the need for cooperation and coordination with suppliers, nonprofits, and even competitors to achieve their objectives. Partnerships, joint ventures, cooperatives, and other business entities have recognized that organizational goals can often be more effectively and efficiently achieved by entering into agreements with others.

These types of arrangements often involve outreach efforts (communicating or marketing to an audience or public), which have their own peculiarities in the field of marketing. As the engineering community embarks on a campaign to "change the conversation" and promote engineering to young people and the general public, it might be helpful to draw upon lessons learned from other coordinated outreach campaigns.

Definitions

There is no universally accepted definition of a coordinated outreach campaign, although there are many good examples of them. However, one definition that encompasses the broad range of outreach would be *any communication/advocacy/marketing/branding/promotional effort involving more than a* *single entity working cooperatively and with a unified message strategy to achieve a single goal or serve a shared interest.*

The heart of a coordinated outreach campaign is in the words "working cooperatively and with a unified message strategy to achieve a single goal or to serve a shared interest." As these words imply, there must be (1) a reason for entering into a coordinated outreach campaign (e.g., a problem that must be solved or an opportunity to be pursued) and (2) a commitment to working cooperatively.

A coordinated campaign might influence federal spending on R&D or support for STEM education.

The words "unified message strategy" are essential, because this strategy is what makes an outreach effort a *campaign*. These words suggest that planning is involved and that messages are designed to meet the goals of the campaign. The message strategy is also important because it is based on recognition of the role of the target audience, from whose perspective the campaign must be understood to be about a single thing and not about the different points of view of the participating entities.

According to *Raising Public Awareness of Engineering* (NAE, 2002), the engineering community as a whole spent hundreds of millions of dollars to promote public understanding of engineering, but because the messages were not developed as a unified campaign, they were not very effective. A subsequent report, *Changing the Conversation* (NAE, 2008), recommended a unified voice for the engineering community in the form of an overall message strategy.

There are many reasons for entering into a coordinated outreach campaign. Some of the more prominent ones are discussed below.

Reasons for Launching a Campaign

Increasing Demand

Got Milk? is the quintessential example of a coordinated outreach campaign. Initiated by the California Milk Processor Board in 1993 to increase milk consumption in California, it was adopted by dairy boards around the country, and by all accounts, it has been a success. Awareness of the campaign, which continues to this day, reached 90 percent by 1995 (*www.gotmilk.com*) (Manning, 2006).

Got Milk? is a "generic product promotion," that is, a campaign to increase sales by focusing on a product category, leaving brand promotion to individual participants in the campaign. This kind of campaign can increase demand, thereby improving the marketing environment for an entire industry. This is often referred to as "increasing the size of the pie," which means that each member's piece gets larger, but the percentage share is not necessarily affected.

Commodity foods have been the subjects of coordinated campaigns for decades (e.g., *Beef, It's What's for Dinner*; *Pork, the Other White Meat*; *the Incredible Edible Egg*; *Orange Juice, It's Not Just for Breakfast Anymore*). These campaigns, which have been highly visible because they target the general public, require large budgets. Many are legislated, and participation by farmers and producers may be mandated to ensure that sufficient funding is available for the campaign to have the desired impact.

Influencing the Legislative and Regulatory Environment

Commodity campaigns are not just for food products, although these may be the most recognizable examples. Industry associations also undertake such campaigns to monitor and influence the industry's legislative and regulatory environment. Although much of the communication is through direct contact with policy makers, efforts sometimes spill over into the realm of customers, the workforce, or even the general public.

For example, an association may use a coordinated outreach campaign to advocate for certain issues (e.g., environmental issues) and bring the discussion to the broader voting public. Sometimes these kinds of campaigns take on the appearance of public service announcements to forestall government regulation. A prominent example is a responsible-drinking campaign funded by the alcohol industry.

For the engineering community, a coordinated campaign might be aimed at influencing federal spending on R&D or support for university engineering programs or STEM programs in local school systems.

Workforce Recruitment

Coordinated outreach campaigns might also be used to promote workforce recruitment. In some industries and professions, competition for employees can be every bit as fierce as competition for customers. Just as generic product promotion can increase demand for a product, workforce-focused coordinated outreach campaigns can increase the supply of potential employees.

In some cases, societal trends, such as immigration, education, or demographic or lifestyle changes, affect the workforce. These issues are best addressed on the industry (or profession) level. In other cases, the image of an industry or profession may keep people from entering that particular field.

Workforce issues are a key focus of outreach efforts for the engineering community, but this issue must be approached on two levels. A coordinated campaign can help stimulate interest among students to pursue engineering degrees and careers, but for such a campaign to be effective, there must also be an overall change in the way engineering is perceived.

Image Building

General image building can be part of generic promotion and the workforce issue, or it can be the primary purpose of a campaign. Some industries or professions (e.g., funeral directors, the oil industry after the BP spill) have a high threshold to cross to create a positive public image.

Image building campaigns can be "external," that is, the target audience may be important to the industry even though it is not directly related to it (e.g., customers, potential workers, legislators). Or the campaign can be "internal," that is, directed to people currently in the industry to improve morale or increase professional pride. General image campaigns may follow a crisis that befalls an industry, a time when pooled resources and a unified voice can be more effective than individual voices.

Other Goals

A campaign to change the conversation about engineering will have several goals. It will certainly address the workforce issue, but it must be much broader than that. Encouraging young people to pursue careers in engineering will require that the profession also have a favorable image and that the public have a better understanding of what engineers do.

The engineering community must develop a unique, favorable, compelling brand identity that convinces the target audiences to view engineers and engineering in a new way. The beneficiaries of this campaign will be not only the engineering community, but also, ultimately, the country as a whole, which urgently needs large numbers of well educated engineers to support U.S. competitiveness and a sound economy (Box 1).

BOX 1

In the 21st century, our nation should have a vibrant economy, a healthy and secure populace, and a high standard of living. To meet this goal we must increase the quantity, quality, and diversity of our engineering workforce. To achieve that, we need to change the way people perceive and talk about engineering.

– **NAE President Charles M. Vest**
(*Changing the Conversation* website, *http://www.engineeringmessages.org*)

Challenges to Coordinated Outreach Campaigns

Implementing a coordinated outreach campaign raises many challenges, primarily because of the need for coordination among participating entities that may have complicated relationships. Is there already a management or organizational structure, or does one have to be established to administer the campaign? How loosely/formally organized is the industry or community? How diverse are the entities in terms of role, size, and stature? Will the individual entities benefit equally from the coordinated effort?

Participants and Decision Makers

The first of many challenges is *determining who will be involved* in the campaign and who will make *decisions*. For campaigns by existing industry associations, professional societies, or other alliances, these questions probably will not arise. For other campaigns, the players must be identified and encouraged to participate.

For the engineering community, the players, or participants, have been defined broadly in an NAE project called Changing the Conversation: From Research to Action (*http://www.nae.edu/Activities/Projects20676/26426/20762.aspx*):

"Engineering community" refers to the broad set of organizations that either (1) develop or support the development of engineering talent, (2) employ engineers in substantial numbers, or (3) have as a major part of their mission communicating with the public about engineering and related technical subjects. These organizations include: schools of engineering; engineering professional societies; technology-intensive industries; industry associations; federal agencies and R&D laboratories; design and contracting firms; certain print, broadcast, and Internet-based media; and museums and science and technology centers.

This all inclusive definition identifies stakeholders in the campaign. However, the question of control (i.e., planning, implementation, and decision making) must still be answered. With such a variety of subgroups (industry, schools of engineering, federal funders of R&D, etc.), which probably have different fundamental goals and target audiences, the decision concerning control presents a considerable challenge.

The more disparate the stakeholders, the more difficult it is to identify and account for competing interests.

Competition

Competing interests are unavoidable in dealing with multiple entities, and working cooperatively goes against normal business practice in most situations. In engineering, there may be competition for consulting projects among companies, but more important, there may be competition for engineers to fill jobs. In addition, engineering schools must compete for students, and engineering societies try not only to build their memberships but also to attract students to their disciplines.

Competing interests might also affect the messages or goals of a coordinated campaign. The interests of a museum, for example, may be very different from those of an engineering school or a Fortune 500 company or a federal agency. The more disparate the stakeholders, the more difficult it is to identify and account for all competing interests.

Funding

There are several ways of funding coordinated outreach campaigns, from mandated "check offs" or levies to voluntary dues to angel funding. Competing interests among the participants can make funding more challenging because the perceived benefits for different interests are often difficult to quantify. In addition, the organizational infrastructure of the campaign may be loose or unclear.

The newness of a situation (e.g., a "first-ever campaign" to promote something) might also make it more difficult to secure financial support. In these situations, external funding (e.g., from the National Science Foundation) or internal funding from a single source (e.g., a so-called "angel") may be the most viable options, rather than mandatory, or even voluntary, contributions from each member.

For the engineering community, because of the absence of a single organization with the authority to levy a fee, funding will likely be on a voluntary basis. This presents a serious challenge but does not make the campaign impossible.

Consistency and Coordination

Perhaps the most important challenge in implementing a coordinated outreach campaign is maintaining consistency and the coordination this requires. From the perspective of the target audiences, the campaign must be unified, and to have the greatest impact, the message must be delivered in a consistent way. The more entities involved and the less formalized the organization, the more difficult it is to coordinate activities and ensure that the message is uniformly delivered and activities are executed as planned.

Coordination must be achieved through the *support* of the participating groups. A concerted effort must be made to convince all stakeholders to use campaign materials and incorporate the message into their activities. In other words, a communication or educational campaign must be targeted to stakeholders first to persuade them of the value of the campaign.

Stakeholders must become the gatekeepers of the campaign. They must be convinced that (1) the overall mission and goals are valid and worthwhile; (2) the methods of achieving those goals are effective; and (3) the campaign will not adversely affect their marketing efforts. They must feel that messages and materials are in keeping with their own organization's image and that they blend well with their marketing or communication efforts. The importance of meeting this challenge cannot be overstated.

The recently launched Changing the Conversation website (*www.engineeringmessages.org*) is intended, at least in part, to address consistency and support challenges. The site not only provides messages for the campaign and some recommendations on how the messages should be used, but it also encourages the players to share experiences and learn the most effective ways to incorporate the messages into their own outreach or marketing efforts. The latter will be a critical element to the success of the campaign.

Measuring Effectiveness

All outreach campaigns should be evaluated to determine their effectiveness. The metrics depend on the objectives or purpose of the campaign. Typically, the most stringent measure is the actual outcome of the campaign. For example, generic product promotion campaigns are implemented to increase sales, so sales would be the *outcome measure*. Legislative campaigns are attempts to impact the legislative process and can be judged by their success on that score.

For campaigns that seek to promote an opportunity rather than fix a problem, the outcome may be elusive, because there is no point of comparison—essentially no "control group" in the experiment—because we do not know what the result would have been if there had been no campaign.

For image campaigns, the outcome may be even more difficult to determine, or it may be difficult to attribute changes directly to the campaign. For example, the results of a campaign to encourage young people to become engineers may not be apparent for a decade. The goals of "sustain[ing] the U.S. capacity for technological innovation" and "improving technological literacy" (NAE, 2008) will be a challenge to measure on their own, but given the number of variables, correlating results with communication efforts and determining causation will be nearly impossible.

Therefore, other measures may be used to determine the effectiveness of a campaign. For example, *process measures* focus on the effort expended in the campaign (e.g., how many times was a message used, how many articles were written using the message, how many visits to the website, etc.).

Impact measures can indicate whether a campaign actually had an effect or impact on the target audience. Typically these include measures of awareness, knowledge, and attitudes.

One goal of the Changing the Conversation campaign is to encourage young people to go into engineering. Before a young person can make that decision, s/he must be aware of engineering as a field, be knowledgeable enough to make a sound decision, and have a favorable attitude toward the career. These may not be entirely predictive of a youngster actually entering the field, but they are necessary to making the decision. For the goal of improving technological literacy, awareness of the role of engineering in innovation, or even the image of engineers in society, may indicate that the campaign has had an impact.

Essential Conditions for Success

The engineering community's efforts to change its public image are in some ways more challenging and ambitious than those of other coordinated outreach campaigns. The disparate nature of the stakeholders, the lack of a single coordinating mechanism, and difficult funding issues all contribute to the challenge, but there are three areas the engineering community should focus on to ensure success: the message strategy, the frequency and consistency of message delivery, and the mechanism for coordination and control.

The results of a campaign to encourage young people to become engineers may not be apparent for a decade.

The Message Strategy

The messages used in the campaign must be based on a sound strategic foundation that will resonate with the target audience. This is true of any campaign, but it is especially important for a coordinated campaign in which the target audience cannot rely on an organization or existing brand image to define the campaign. The message strategy unifies the campaign.

For the engineering community, there will be several specific messages, but they must be closely related and based on an overarching positioning statement (Box 2) for the engineering brand. Specific messages, taglines, and even visual presentations should tie into this strategy. The engineering community is in a strong position to succeed because its message strategy is based on sound research about the target audience conducted by the Bemporad Baranowski Marketing Group (BBMG) and presented in *Changing the Conversation* (NAE, 2008).

BOX 2
New Positioning Statement for Engineering

No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people's everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21st century.

Changing the Conversation (NAE 2008)

Frequency and Consistency

Frequency is essential to ensuring that messages are effective in persuading individuals to act. Especially in an environment in which the target audience is being bombarded by information, a consistent message is essential to breaking through the clutter and reinforcing awareness and attitudes.

The large, varied engineering community encompasses many players who are interested and dedicated to this cause, and the sheer size of the community and its resources has the potential to bring its messages to a wide audience. If most of the stakeholders adopt the same messages and use them consistently in even a portion of their marketing or outreach efforts, the campaign could achieve the necessary frequency to ensure success.

Mechanism for Coordination and Control: Educating Stakeholders

To ensure frequency and consistency, there must be a mechanism for coordinating activities. Stakeholders need an incentive to use the messages and support the campaign. They also need to be given tools, knowledge, and resources for using the messages and materials in the right way. Stakeholders must be convinced that the campaign will benefit them, which may require an educational campaign directed to them to explain potential benefits of the campaign as specifically as possible. Even though a large portion of the engineering community may agree that a campaign is necessary, many may still have to be convinced that they themselves will benefit.

An important part of the education process is to show results. Stakeholders may be more likely to participate if there are some short-term successes. Once they see tangible results, the risk of participating will be reduced.

The engineering community is already in the early stages of the educational process. The *Changing the Conversation* website can be a focal point of the campaign, ensuring control over messages by educating the many players in the community on the best way to use them, as well as on the need for the outreach campaign. By harnessing technology and embracing the changing media landscape, the website can reduce the amount of funding necessary for the campaign, provide an effective method of reaching younger audiences, and improve monitoring of results.

A single, central coordinating body would simplify the communication of messages to the target audience. Possible leaders of a coordinated outreach campaign for engineering include NAE, the National Society for Engineering Education, or an existing or new coalition, such as Change the Equation, which was recently established by President Obama.

Even though this kind of outreach activity is not a primary mission for any of these organizations, they may be in a position to coordinate parts of the effort if not the entire campaign. Opinion leaders and influential people in the engineering community can also play a leadership role, particularly in influencing stakeholders to participate in the campaign.

A Hopeful Conclusion

Although the engineering community faces many challenges, none of them is insurmountable. Indeed, achievements to date have set the engineering community's campaign in the right direction. First, the need for a coordinated campaign has been identified and well defined. Second, the messages that have been developed are strong and based on solid research. Third, the importance of consistency and frequency is clearly understood. Finally, the community is actively engaged in determining the best methods to ensure the success of the campaign.

References

Manning, J. 2006. *Got Milk?* marketing by association. Associations Now (July). Available online at *http://www.asaecenter.org/Resources/ANowDetail.cfm?ItemNumber=18644*.

NAE (National Academy of Engineering). 2002. Raising Public Awareness of Engineering. Washington, D.C.: National Academies Press.

NAE. 2008. Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington, D.C.: National Academies Press.

The University of Colorado Boulder TEAMS Program reaches thousands of youngsters annually.

Who Should Be an Engineer?

Messaging as a Tool for Student Recruitment and Retention

Janet L. Yowell and
Jacquelyn F. Sullivan

Janet L. Yowell

Jacquelyn F. Sullivan

Choose a job you love, and you will never have to work a day in your life.

—*Confucius*

Being an engineer takes creativity, hard work, and perseverance. As Marie points out in the excerpt below, excelling in engineering, as in other professions for which excellence is the goal, also takes desire.

> "Why do you want to be an engineer? It is sooo hard!" Marie, a current Ph.D. engineering student at the University of Colorado Boulder, was asked this question by a young woman she was mentoring through a local community education program. "Anyone can be an engineer," Marie answered. "You can do it also. You just have to *want* to do it."

According to educational researchers, compared to people in other professions, K–12 students and teachers have a poor idea of what engineers do (NAE, 2008). And no wonder! Take a look at the TV lineup of sitcoms, most of which are based on the lives of physicians, lawyers, investigators, and police officers. Few media outlets provide opportunities for people to be entertained or informed about the lives of engineers.

Consider some real-world examples we've encountered when implementing our NSF-funded GK-12 TEAMS (**T**omorrow's **E**ngineers . . . cre**A**te.

Janet L. Yowell is associate director of K–12 engineering education, and Jacquelyn F. Sullivan is associate dean of engineering at the University of Colorado Boulder.

Figure 1 CU Boulder Engineering Fellow, Abigail Watrous, and 6th grade student, Humberto.

i**M**agine. **S**ucceed.) Program at the University of Colorado Boulder:

> A 4th grade girl, learning for the first time about engineering, asks her University of Colorado engineering fellow,[1] "Miss Jodi, can engineers wear make-up?" Jodi, a master's student in chemical engineering, replies, "You bet they can."
>
> An enthusiastic 6th grade Latino boy shyly approaches his engineering fellow and asks, "Miss Abby, can engineers have Mohawks?" Abby, a Ph.D. student in civil engineering, replies, "Yes, Humberto,[2] they sure can! Engineers can wear their hair any way they want!"

Humberto and many other Latino boys in his middle school are bringing back the Mohawk hair style with passion and creativity—honing their skills by practicing and sharing ideas among friends (Figure 1). *Passion. Creativity. Practice. Sharing ideas.* If we stretch our thinking, the creation of a 6th grader's Mohawk has characteristics in common with the innovation process that underlies engineering.

The steps in the creation of Humberto's Mohawk are loosely analogous to the steps in the engineering design cycle: identify the problem *(need a bold hairstyle)*, brainstorm design solutions *(lots of popular hair styles out there)*, select a design to prototype *(Mohawk style, short length)*, create/build, analyze, test, and iterate *(do it again and again until you meet your requirements and you look cool)*. From this perspective, Humberto might be an engineer in the making, He is already applying *creative processes* that could be used in engineering design.

Humberto's original question, "Can engineers have Mohawks?" is loaded with possibilities, as he explores his own identity as a future engineer. In a way, he is already asking "Can *I* be an engineer?" Yes, indeed . . . who really belongs in engineering?

The Problem—or Challenge

The United States has to do a better job of identifying and nurturing mathematically talented young people, regardless of their gender, race, or national origin (Hyde and Mertz, 2009). As stewards of K–12 engineering education, counselors and teachers often raise concerns about the *type* of student who might become an engineer. If we received a dollar for every time we have been asked by a student, teacher, or parent, "Can my child be an engineer?" or "What type of student can endure the rigorous study it takes to be an engineer?", we could reduce our fundraising to a minimum.

Unfortunately, we disadvantage our nation's young people during their identity-forming years by referring to engineering as a "rigorous," math-dominant, "unattainable" career. Rarely, if ever, do we hear the medical profession marketed by emphasizing that becoming a doctor takes "years of rigorous study."

In addition, people believe that by becoming doctors they will be helping others. But engineers, whose efforts also contribute to the health, happiness, and well-being of society, are not widely known as people who help others. At best, we market engineering as "problem solving"—which pales in comparison to *helping people* in the minds of young people . . and adults.

Based on a perception of the gender-appropriateness of certain occupations, children may start to think about "jobs" and form their career identities as early as 3rd grade (Turner and Lapan, 2005). They wonder if they will grow up to be policewomen, teachers, ballerinas, dentists, basketball players, or, especially, doctors. They seldom imagine that they will become engineers. Their early perceptions of engineering—if they are even aware of the field—are of a not-so-fun *job* that can only be done successfully by people who *love both math and science*.

On average, girls and women tend to prefer working with people, whereas boys and men tend to work with things (Lubinski and Benbow, 2006). Research for the 2008 NAE *Changing the Conversation* study revealed that young girls preferentially select images of women

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[1] The University of Colorado Boulder Graduate STEM Fellows in K–12 TEAMS Program is funded by the National Science Foundation, GK-12 grant no. DGE0946502, and private foundations.

[2] Not the student's real name.

doing engineering, whereas boys select images of *things* that represent engineering.

If these tendencies are representative, then engineering *should* be appealing to both boys *and* girls, because engineers work with both things *and* people. But this obviously isn't so. Women do not flock to engineering colleges clamoring to get in, but men do.

Therein lies the challenge—correcting a misunderstanding about what engineers do that results in an inability to attract representative numbers of individuals from all sectors of our population. Even though engineering is in dire need of diversifying to reflect the richness of our rapidly-changing demographics, and even though we are a nation in which women preferentially attend college and students of color are the large majority in many K–12 schools, we fail to attract either to attend engineering schools in quantity.

To meet the need for an adequate, diversified, educated engineering workforce by 2020, engineering colleges and the engineering profession must adapt *now* to ensure that engineering is appealing to people from all walks of life—young people, to be sure, but also the people who influence their early academic choices. Teachers, counselors, parents, and society at large must embrace the idea that engineering is a helping profession and that, to a large extent, it shapes the health and welfare of people everywhere, as well as the health and welfare of our planet.

The Myth

Over the past decade, the TEAMS Program at the University of Colorado (CU) Boulder has engaged thousands of girls and boys in grades 3–12 in weekly hands-on, standards-based engineering lessons and activities that inspire discovery and innovation. As custodians of engineering education in this early stage of the value chain, the same questions emerge year after year among K–12 students: Must engineers love math? Can *I* be an engineer (sometimes embedded in questions such as "can engineers have Mohawks")?

The answer to the math question is no, engineers do *not* have to love math. They do, however, have to develop competent math skills and *know how to use math* concepts. Consider how different a child's early perception of engineering would be upon hearing that she does not have to *love math* to imagine her future as an engineer. Perhaps she is a capable math student but does not particularly love it—any more than a budding physician might imagine loving organic chemistry. Sadly, a parent or educator may perpetuate the myth that she must love math to pursue engineering and dissuade her from preparing for an engineering future for fear that she will fail because she does not love *the rigor* of math.

In reality, not only can she become an engineer, but even if she at most likes math, she is likely to outperform her male counterparts in college and graduate school and earn a grade point average at or above the mean for her school (Lord et al., 2009). *Love of math* pales in comparison to her competent *doing of math*. And yet, that lack of *love* for math may be a show stopper for many, many girls. And boys. That's one misunderstanding we can all help fix.

Engineers don't have to love math any more than physicians have to love organic chemistry.

Although young women dominate the top deciles of U.S. high school graduates, they have a minimal presence among high school students who imagine pursuing careers in engineering (Sullivan, 2006). The persistent absence of a substantial female—and minority—presence in our male-dominated field, a long-recognized issue in higher education, has fueled the debate about gender equity, social justice, and professional diversification (Lord et al., 2009; Watson and Froyd, 2007). To increase the presence of women and underrepresented minorities in the engineering landscape (output), engineering programs must attract them in droves (input). And while we are at it, we should also focus more on first-generation college-bound students.

Among many environmental and cultural influences, poor self-efficacy (i.e., and nagging suspicion, common in females, of being unable to perform) low academic self-esteem, and early misperceptions of engineering influence a female student's educational attainment and choice of career (Buchmann et al., 2008; NAE, 2008). The same is true for Latino, American Indian, and African American students, all of whom are also underrepresented in the engineering profession (Lord et al., 2009). These students don't need "fixing" to find a home in engineering. But our system needs fixing, if we expect to tap into the rich diversity of experience and perspective that today's 3rd graders (the fall 2020 entering engineering class) could bring to our profession.

Engineering and the Future

Engineers want to be perceived by the public as members of an important, challenging, helping profession that contributes to society. However, many people have difficulty separating "engineering" from "science" and "technology" (NAE, 2011). An early lesson in the University of Colorado Boulder TEAMS Program, which reaches thousands of youngsters annually, is the importance of distinguishing between science and engineering, which we often characterize as follows: scientists explore the universe and investigate that which already is, and engineers create that which has never existed before. In essence, engineers create "stuff"—new knowledge, new things, new processes—that address the wants and needs of people and our planet. Young people are fully capable of understanding the difference.

According to the U.S. Census Bureau, by 2050, about half of the U.S. population will be nonwhite. This will mean that engineering solutions must meet the needs and desires of more diverse consumers (Sullivan, 2007). This will also mean that to maintain U.S. technological capability and capacity, the engineering profession will have to draw more heavily on individuals from underrepresented groups (NAE, 2011).

The question is how we can undo centuries of unintended ignorance about engineering and initiate systemic change.

However, our goal of drawing on a diverse citizenry will not be realized as long as minority women and men—and women of all ethnicities—continue to reject engineering futures. So how can we prepare and recruit a talented population representative of our nation's rich demographic makeup into the engineering fabric? For starters, we must change the messages that pervade our society about engineering, who engineers are, and who they should be.

As we have seen, both adults and teens strongly associate engineering with mathematics and science skills much more than with problem solving, creativity, or having a positive impact on the world (NAE, 2011). Even though engineering is about *doing things for the benefit of society*, teens—and adults—rarely make that connection.

It is frustrating to have to remind the public that virtually every technology engineers design/create is intended to meet a societal need or desire and that most safety-related technologies—from airbags and the air traffic management system to food handling equipment and smoke detectors—were designed by engineers (NAE, 2011). The availability of clean drinking water is taken for granted, and the capability of loading more than 10,000 songs onto an iPod® is an expectation.

To offset the embedded (mis)perceptions about engineering and the engineering profession, something must change—and that change must be systemic and pervasive in our schools, homes, and culture. The question facing us now is how we can undo centuries of unintended ignorance about engineering and initiate systemic change.

Technology is pervasive in the lives of teenagers: 62 percent of 12 to 17 year olds use the Internet to read about current events or politics; 48 percent shop online; and 75 percent have cell phones (Lenhart et al., 2010). The disconnect between our nation's young people, who are *using technology* at an increasing rate and those who are looking for opportunities to be agents of change at the forefront of *creating technologies* is astonishing. As long as young people do not know much about engineering or have a skewed view of what it means to be an engineer—or even who belongs in the profession—we cannot expect them to seriously consider careers in engineering (NAE, 2011).

Changing the Conversation

Raising Public Awareness of Engineering (NAE, 2002) and *Changing the Conversation* (CTC) (NAE, 2008) have provided a pathway toward enlightening students, parents, and teachers about the creativity and inspiring nature of engineering. They also address the importance of informing the public about opportunities afforded by engineering and encouraging K–12 students to pursue futures in engineering.

Even though the number of women in higher education is skyrocketing, a shocking 1.6 percent of them complete undergraduate degrees in engineering (NSB, 2010; Snyder et al., 2009). This statistic reflects a broken K–16 educational system that is not poised to serve our nation's—or our planet's—future.

If we can take the information learned through the CTC study and implement strategies throughout our industry and educational system to inform and increase awareness of a positive image of engineering, we might, slowly, but eventually, realize a shift in students' thinking about engineering futures. Only then can we expect an appreciable change in *who* and *how many* choose to pursue engineering futures.

Implementing an Engineering Messaging Campaign at the University of Colorado Boulder

Beginning in 2008, the CU College of Engineering and Applied Science overhauled its recruiting and marketing materials to capitalize on the CTC messages and preliminary taglines and married them with the whimsical, stylistic graphics created by the WGBH *Engineer Your Life* (EYL) (*http://www.engineeryourlife.org*) campaign to create postcards, flyers, and web-based tools that resonate well with younger audiences and adults. The communications materials make use of fun, funky fonts; bold, vibrant colors; and gender-friendly colors (even some flowers); and images of people interacting with technologies to highlight the relevance of engineering for young people.

These strategic, contemporary designs, coupled with well-messaged words on flyers about engineering events have stimulated interest among female and minority students to take a look at—and ultimately attend—our engineering college, thus substantially expanding participation. Attendance at both Diversity Sampler, a minority student-focused recruiting event (Figure 2), and Women Explore Engineering day, a one-day program for high school girls, quadrupled this year alone.

Concurrently, in late 2008, we combined EYL designs with images of our diverse engineering students in their lives beyond academics and CTC messages to create "messaged" recruiting postcards (Figure 3).

Although it is impossible to determine the exact impact of changing our messaging to be more engaging and relevant, our enrollment of women engineering students in fall 2009 and 2010 increased sharply—from our five-year average of 19 percent to more than 24 percent. At the same time, enrollment of minority students was up 67 percent in 2010 over our prior five-year average and is on target to be even higher for 2011. Anecdotal

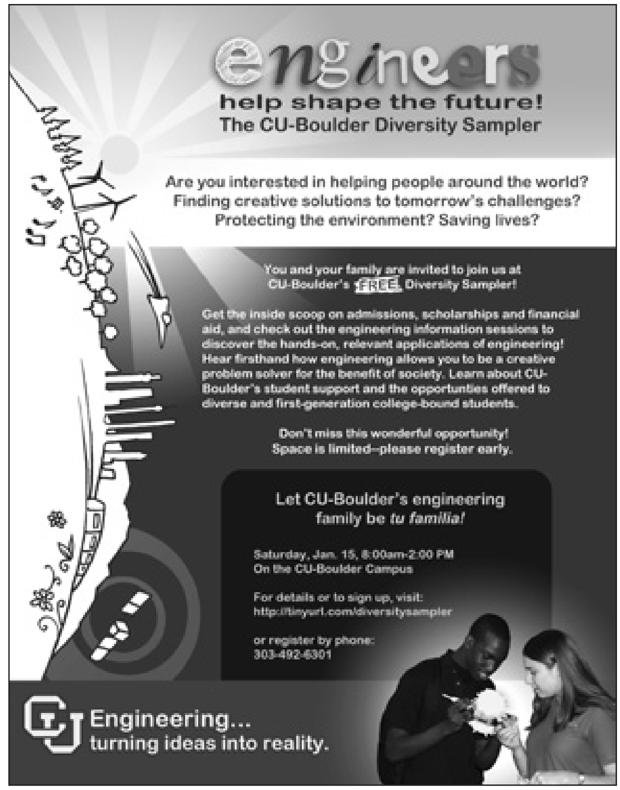
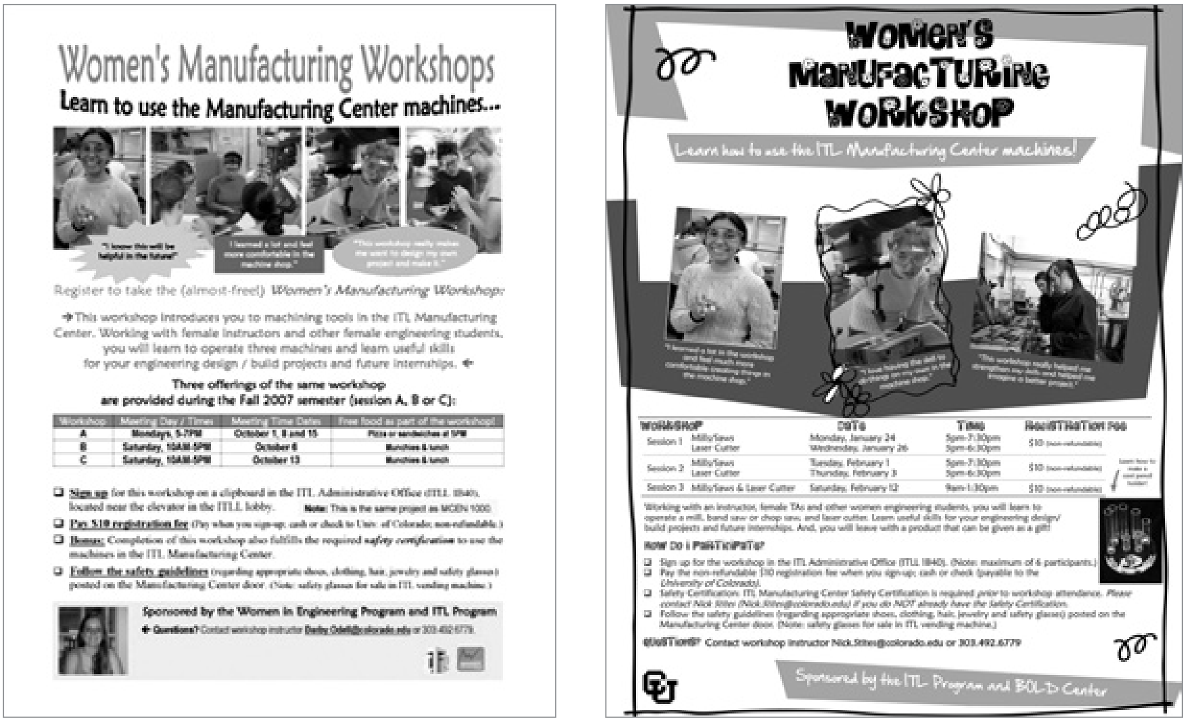


FIGURE 2 "Messaged" flyer for the CU Boulder Diversity Sampler activity.

evidence also suggests that the recruiting pieces and consistent theme of "Be an Engineer" catch the eye of college-bound teenagers and positively impact recruiting outcomes.

Feedback suggests that the CTC messages and taglines effectively inform audiences that engineering is a fun, rewarding career about *helping others and shaping our planet*

FIGURE 3 "Messaged" recruiting postcard that combines EYL designs and images of engineering students outside the classroom.



a. b.

FIGURE 4 a. The *before* flyer for the Women's Manufacturing Workshop. b. The *after* "messaged" flyer for the same event.

and that it deserves further consideration as a personal pursuit. Teachers and parents frequently tell us that they wish they'd known engineering was that interesting and could go back themselves and become engineers.

Messaging materials continue to be refined at CU Boulder, and the CTC messages continue to drive *all* aspects of our recruiting—every letter, every presentation, every poster, every program flyer. Our initiative has been greatly improved by the addition to our team of a graphic designer who has given the messages a youthful, society-focused look.

The CTC messages encapsulate who we are as engineers and how we view the role of engineering in the world. CTC has not only changed our conversation but has literally changed *us*. Every bit of recruiting material from our college—including presentations by deans—is augmented with the CTC messages and/or taglines and is designed to "hook" young people on the *giving back* aspect of an engineering future. And, in so doing, we as deans are also energized by the messages we deliver.

The four messages that tested best in the *Changing the Conversation* (NAE, 2008) study are:

- Engineers are creative problem solvers.
- Engineers make a world of difference.
- Engineering is essential to our health, happiness, and safety.
- Engineers help shape the future.

The seven preliminary taglines are:

- Turning ideas into reality
- Because dreams need doing [which tested best across genders]
- Designed to work wonders
- Life takes engineering
- The power to do
- Bolder by design
- Behind the next big thing

Internal communications at CU Boulder have also changed significantly. For example, attendance at our undergraduate Women's Manufacturing Workshops tripled this year after we implemented a new recruiting flyer that combined the EYL template, CTC findings, and (shamelessly) flowers (Figure 4). We like that outcome!

Fun, well-messaged flyers inviting current engineering students have helped to increase attendance at myriad community events. But our goal isn't just fun. Our hope is that these efforts to *build community* will ultimately improve retention of our engineering students.

Conclusion

The engineering community can, and must, figure out how to market our profession to attract talented, well prepared women and underrepresented minorities. Ultimately, this will change the engineering landscape and help sustain U.S. capacity for technological innovation, interest young people in engineering careers, and improve technological literacy (NAE, 2008). The CTC report and the engineering profession have issued a call to action to help change perceptions of engineers. However, it will take all of us—educators, professional engineers, industry, government, and researchers—working together to make that change a reality—and we need results now.

It's time for years of public misperceptions about engineering to be unraveled and to put in place *strategic, consistent practices* to change the future of engineering in our nation. We can start by asking ourselves if it is time to change the conversation in *our own* organizations.

Acknowledgment

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References

Buchmann, C., T.A. DiPrete, and A. McDaniel. 2008. Gender inequalities in education. Annual Review of Sociology 34: 319–337.

Hyde, J.S., and J.E. Mertz. 2009. Gender, culture, and mathematics performance. Proceedings of the National Academy of Sciences 106(22): 8801–8807.

Lenhart, A., K. Purcell, A. Smith, and K. Zickuhr. 2010. Social Media & Mobile Internet Use Among Teens and Young Adults. Pew Internet & American Life Project, February 3, 2010.

Lord, S.M., M.M. Camacho, R.A. Layton, R.A. Long, M.W. Ohland, and M.H. Washburn. 2009. Who's persisting in engineering? a comparative analysis of female and male Asian, Black, Hispanic, Native American, and white students. Journal of Women and Minorities in Science and Engineering 15: 167–190.

Lubinski, D., and C.P. Benbow. 2006. Study of mathematically precocious youth after 35 years: uncovering antecendents for the development of math-science expertise. Perspectives on Psychological Science 1(4): 316–345.

NAE (National Academy of Engineering). 2002. Raising Public Awareness of Engineering. Washington, D.C.: National Academies Press.

NAE. 2008. Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington, D.C.: National Academies Press.

NAE. 2011. Engineers–How Are You Changing the Conversation? The CTC Community. Available online at *http://www.engineeringmessages.org/*. Accessed April 21, 2011.

NSB (National Science Board). 2010. Science and Engineering Indicators 2010. NSB 10-01. Arlington, Va.: National Science Foundation.

Snyder, T.D., S.A. Dillow, and C.M. Hoffman. 2009. Digest of Education Statistics 2008. NCES 2009-020. National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, D.C.

Sullivan, J.F. 2006. A call for K–16 engineering education. The Bridge 36(2): 17–24.

Sullivan, J.F. 2007. Lessons from the sandbox. PRISM, American Society for Engineering Education 16(5). Available online at *http://www.prism-magazine.org/jan07/last_word.cfm*.

Turner, S.L., and R.T. Lapan. 2005. Evaluation of an intervention to increase non-traditional career interests and career-related self-efficacy among middle-school adolescents. Journal of Vocational Behavior 66: 516–531.

Watson, K., and J. Froyd. 2007. Diversifying the U.S. engineering workforce: a new model. Journal of Engineering Education 96(1): 19–32.

WGBH is using the multimedia resources of two major projects to engage young people in innovative ways.

Engineering a Change in Perception

Engineer Your Life and *Design Squad*

Marisa Wolsky is executive producer at WGBH Educational Foundation.

Marisa Wolsky

In an address to the National Academy of Sciences on April 29, 2009, President Obama challenged his listeners: "I want us all to think about new and creative ways to engage young people in science and engineering…I want you to know that I'm going to be working alongside you. I'm going to participate in a public awareness and outreach campaign to encourage students to consider careers in science and mathematics and engineering—because our future depends on it" (White House, 2009).

Considering that the percentage of students graduating with engineering degrees has been declining steadily (NSF, 2006), especially among women and minorities (in 2007, only 12 percent of bachelor's degrees in engineering were awarded to black and Hispanic students, and just 19 percent were awarded to women [NSB, 2010]), a great deal of work must be done to meet the president's challenge.

WGBH has taken the first steps by developing messages that promote a positive image of engineering and delivering these messages to engage young people in innovative ways through the multimedia resources of two projects—*Engineer Your Life* (EYL) and *Design Squad*. Both projects have had a significant impact on girls and boys from a broad range of backgrounds.

The Importance of Messaging

Imagine you are thinking about buying your first home, and a house with a "For Sale" sign catches your attention. The real estate agent tells you the house will require time-consuming repairs, the rooms are small, the price is too high, convenient public transportation is not available, and so on. Would you make an appointment to see that house? Probably not.

Now imagine you are a high school student thinking about studying engineering. You talk to the only engineer you know, and he says you will have to excel in math and science, take some of the toughest courses the school offers, and so on. Would you choose engineering as your college major? Probably not.

The first scenario is fictional, but sadly, the second occurs every day all over the country. When it comes to engineering, as cartoonist Walt Kelly's Pogo once observed, "We have met the enemy, and he is us."

After years of debate and sporadic, poorly coordinated attempts to attract youngsters, the engineering community realized that damaging, negative stereotypes about engineering would not change unless the community presented more positive, appealing images of the engineering profession and the individuals who work in it. Support for that fundamental understanding was based on a recent report by the National Academy of Engineering (NAE) Changing the Conversation (CTC) Initiative. Among the recommendations in *Changing the Conversation: Messages for Improving Public Understanding of Engineering* was a call for a coordinated national awareness campaign using messaging to change public attitudes toward and understanding of engineering (NAE, 2008).

Addressing the Challenge

In response to calls for action by President Obama, NAE, and others, the WGBH Educational Foundation undertook two major projects, EYL and *Design Squad*, to put the recommendations from the CTC report into practice. So far, the results have been very encouraging.

EYL, which is produced by the WGBH Educational Foundation with major support from the National Science Foundation (NSF), is a national messaging campaign designed to change stereotypes about engineering and engineers. With carefully developed, meticulously tested messages, EYL reaches out to high school girls through a multimedia website (*www.engineeryourlife.org*) and a large social networking presence. (Although the target audience is mainly high school girls, we know anecdotally that boys also visit the website.) The project also provides advice and resources for parents, counselors, college recruiters, and engineering professionals on communicating with young people about engineering careers.

Tackling the engineering image problem is also the driving mission behind EYL's sister project, *Design Squad*. Funded by NSF and numerous engineering foundations and corporations, *Design Squad* is a Peabody- and Emmy-Award winning PBS reality competition show. On each episode, two teams of teenagers design and build projects for real clients—such as cardboard furniture for IKEA, hockey net targets for the Boston Bruins, and low-cost peanut butter machines for a women's collective in Haiti.

A spin-off television series, *Design Squad Nation*, brings the excitement of the original show to children in the United States and around the globe. In 10 episodes, engineer co-hosts work side-by-side with children to turn their dreams into reality. *Design Squad Nation* shows that engineers, who are often pictured as working alone in laboratories or on computers, are active in the real world, take risks, collaborate with interesting people, and using science, math, and technology to solve real problems.

The following sections describe how messaging developed to change engineering stereotypes has been incorporated into the multimedia components of both projects, the impact of this messaging, and what we have yet to learn about inspiring children and keeping them going along the pathway to engineering careers.

When it comes to engineering, as Walt Kelly's Pogo observed, "We have met the enemy and he is us."

The Art of Delivering Messages

As advertisers know, effective messages are powerful tools that can change attitudes and behaviors, whether the target audience is smokers, voters, or buyers. In the case of EYL, the target group is high-school girls, and the goal is to change a legacy of exclusion, or perceived exclusion.

In 2004, members of the engineering community, led by WGBH and the American Society of Civil Engineers, formed the Extraordinary Women Engineers (EWE) coalition to investigate why high school girls, who take math and science classes at the same rate (or higher) as boys and perform as well as or better than their male peers (EWE, 2005), do not choose to study engineering. Members of the coalition included NAE; the National Society of Black Engineers; Society of Hispanic Professional Engineers; Purdue University School of Engineering; University of Texas, San Antonio, School of Engineering; and Construction Management Association of America.

Extensive research conducted by the EWE coalition revealed that, in general, girls do not understand what engineering is or what engineers do, but, nevertheless, think it's "not for them." Many girls described engineering as a "man's profession" and said they had received little or no encouragement to consider engineering careers (EWE, 2005).

Perhaps more surprising, the coalition found that engineers often unintentionally portray their profession and themselves in a negative light. Instead of describing the benefits, rewards, and social value of being an engineer, they stress the importance of superior math and science skills (EWE, 2005). As a result, most girls perceive engineering as a club for boys with a big "Do Not Enter" sign on the door.

In short, the research showed that the way engineers talk about their profession does not align with girls' motivations and career aspirations. Once that became clear, WGBH decided to enlist two market research firms, BBMG and Global Strategy Group, to develop and test various messages that *would* resonate with girls, as well as with boys. (These two firms also crafted the positioning statement, messages, and taglines for the CTC project.)

Engineer Your Life

The four messages that tested strongest for EYL were:

- **Live your life, love what you do.** Engineering will challenge you to turn dreams into realities while giving you the chance to travel, work with inspiring people, and give back to your community.
- **Creativity has its rewards.** Women engineers are respected, recognized, and financially rewarded for their innovative thinking and creative solutions.
- **Make a world of difference**. From small villages to big cities, organic farms to mountaintops, deep-sea labs to outer space, women engineers are going where there is the greatest need and making a lasting contribution.
- **Explore possibilities.** Women engineers often use their skills to go into business, medicine, law, or government. An engineering education will prepare you for many different careers.

These messages have become the basis of EYL's national campaign to make girls aware that engineering is exciting, meaningful, and definitely worth considering as a career. The centerpiece of the campaign is the EYL website (*http://www.engineeryourlife.org/*)—which provides resources for high school girls and their "influencers" (parents, counselors, teachers, and informal educators) about living and working as an engineer.

Highlights include video profiles of young women engineers (Figure 1), descriptions of interesting engineering jobs, and 10 great reasons to become an engineer. EYL's social networking channels include posts and discussions on six different Facebook fan pages—*EYL*, *Creativity*, *Making a Difference*, *Dream Jobs*, *Design*, and *The Engineer's Pledge*. EYL also provides training sessions to ensure that thousands of engineers and educators know how to talk about engineering positively, and effectively, to girls.

EYL has a very broad reach because of the work of its 107 coalition members, who use the project's tested messages in their

FIGURE 1 a. Civil engineer Erin Fletcher builds bridges that reduce traffic noise. b. Energy engineer Tanya Martinez helps Native American communities expand their renewable energy resources. c. Environmental engineer Pam McLeod makes sure tourism is eco-friendly. © 2008 WGBH Educational Foundation.

programming and outreach efforts. Coalition members include all EWE members, as well as other engineering and educational organizations, colleges and universities, and corporations (e.g., 3M, DuPont, Intel, Lockheed Martin Corporation, National Girls Collaborative Project, Science Buddies, and Coalition for Science Afterschool).

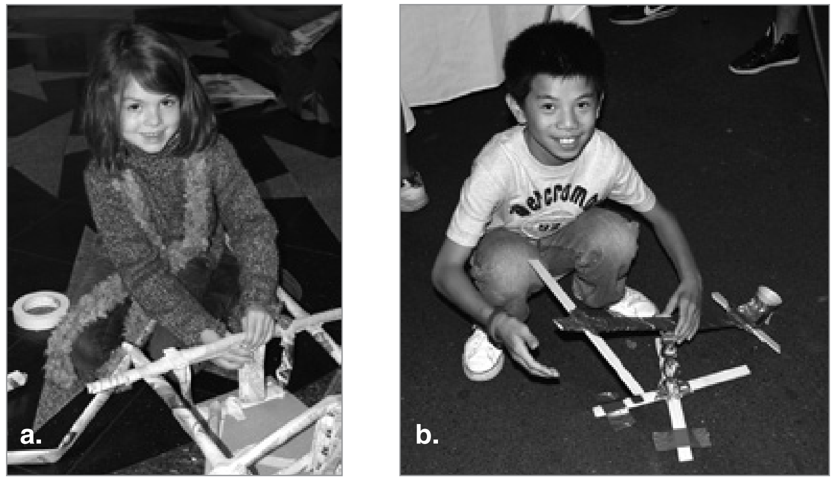


FIGURE 2 a. A young *Design Squad* fan designs and builds a table out of newspaper tubes. b. Kids gain firsthand experience with levers using paint stirrers, wooden spools, and tape to build a device that launches ping pong balls.

Design Squad

Design Squad reinforces and advances the impact of EYL's messaging by promoting the messages through all of its multimedia resources. Since *Design Squad* premiered in 2007, 46 half-hour episodes and 24 short career profiles of engineers have been produced. In addition, an interactive website (*http://pbskids.org/designsquad/*) features streaming video, a multiplayer game (FIDGIT), and an online community of innovators who have contributed more than 65,000 ideas for engineering projects.

To extend its educational value beyond broadcasting, *Design Squad* has conducted 157 training sessions for 6,011 engineers and educators and 453 events and workshops across the country. These sessions feature hands-on engineering activities in which 184,558 children and families have participated (Figure 2). Ninety-one engineering and educational organizations have become formal partners, and 18,804 youth-serving organizations and schools have used *Design Squad*'s educational materials, which include six educator's guides that provide step-by-step directions and leader's notes for 36 activities.

Design Squad series' hosts, who personify the varied, interesting, and inspiring lives of engineers, consistently convey their excitement about engineering. Nate Ball, for example, is a 20-something pole vaulter, jazz pianist, mechanical engineer, grandmaster beatboxer, and co-inventor on six patent applications. His inventions include the Atlas Ascender, a rope-climbing device that enables workers to reverse-rappel at incredibly high speeds for use in search and rescue operations and a refrigeration backpack that can carry massive doses of vaccine to rural areas that have no electric power.

The new co-host of *Design Squad Nation*, mechanical engineer Judy Lee, describes her "dream job" as a product designer at IDEO, an international design and innovation firm in Palo Alto, where she works on a wide range of projects—from children's toys to medical devices to clean water systems for slums in Kenya—and tests products to ensure their safety. Judy has also been profiled on EYL and *NOVA*'s *Secret Life of Scientists and Engineers* Web series (Figure 3).

FIGURE 3 *Design Squad Nation* co-hosts, Judy Lee and Adam Vollmer.

Judy's co-host, Adam Vollmer (also a mechanical engineer at IDEO) is a living example of an engineer with a variety of interests outside his work. He builds his own bicycles, climbs mountains, and explores remote corners of the world. *Design Squad*'s 24 short video profiles introduce viewers to other young engineers who show that engineering is a rewarding, creative career that provides opportunities for working with great people, solving interesting problems, and designing things that matter.

Design Squad also provides *peer role models* for viewers. Contestants and clients from a variety of racial, ethnic, and socio-economic backgrounds address challenges that are not only creative, exciting, and personally fulfilling, but that also make a difference in the lives of others (e.g., designing functional clothing or remote-controlled aquatic pet-rescue vehicles for the New Orleans Fire Department). Moreover, they expose kids to real-world applications of science and math concepts, showing how engineering touches everyday lives and connects with many other careers (e.g., technology, business, art, and fashion).

Summative data show that changing the way engineering is presented does influence children.

One strong message promoted by *Design Squad* in all of its resources is that engineers work collaboratively. Focusing on technology, which facilitates collaboration, *Design Squad* recently created a user-generated content platform and online community where children can share projects, see what others have made, and share their thoughts and reactions. The messages are clear: *You* are creative and can solve problems. *You* can make things that help people. We want *you* to join *Design Squad Nation*. Let's dream big. Let's build something together!

Like EYL, *Design Squad* provides educational resources and training for adults who work with kids. Educator's guides for informal and formal educators (many of whom do not have backgrounds in engineering) provide guidelines and exercises for teaching design skills in afterschool settings and simply talking to kids about engineering.

Face-to-face training sessions have given engineers—many of whom have little experience working with kids—tips on group management and communicating enthusiasm for engineering. ("Tell them your favorite thing about being an engineer. Is it working with people? Is it seeing your ideas and creations come to life? If you share this with kids, you'll give them a whole new perspective on engineering.")

Motivational Messages

Summative data demonstrate how changing the way engineering is presented influences children. An independent evaluation conducted by Concord Evaluation Group revealed a perceptible increase among girls exposed to EYL's website and messages in the level of interest in the field of engineering, in using math and science in their future careers, and in doing the kind of work engineers do (Veridian inSight, 2009).

- Girls familiar with EYL were significantly more likely to report that they wanted to be engineers (78.8 percent) than girls who were not familiar with EYL (57.3 percent).
- Girls familiar with EYL were significantly more likely to believe that imagination and creativity and good people skills, writing skills, and public speaking were important to engineering than were girls who were not familiar with EYL.
- Almost all of the girls who viewed the website indicated that it helped them learn about engineering (95.3 percent) and gave them a better understanding of how to prepare for an engineering career.
- Girls indicated that the website had made them more interested in engineering as a career (87.9 percent) and inspired them to take an engineering class in college (75.5 percent).

Evaluations have also shown that *Design Squad* has a significant impact on children's understanding of engineering and attitudes toward engineering. After watching just four episodes of *Design Squad*, children were significantly more likely to agree with three statements about the work engineers do: (1) *engineers help make people's lives better*, (2) *engineers solve problems that affect real people*, and (3) *engineers sometimes have to test their work and start over again*.

Children's negative stereotypes also decreased significantly. After watching four episodes of the program, fewer children agreed that *engineering is boring* or that *men are better than women at engineering*. In addition, children's design process skills improved, and they demonstrated a good understanding of the science and engineering concepts presented in the programs (Goodman Research Group, 2008).

In a subsequent study, students exposed to *Design Squad*'s hands-on engineering activities in afterschool environments showed a significant improvement in their understanding of the engineering design process after the activities; their leaders showed similar improvement (Veridian inSight, 2009).

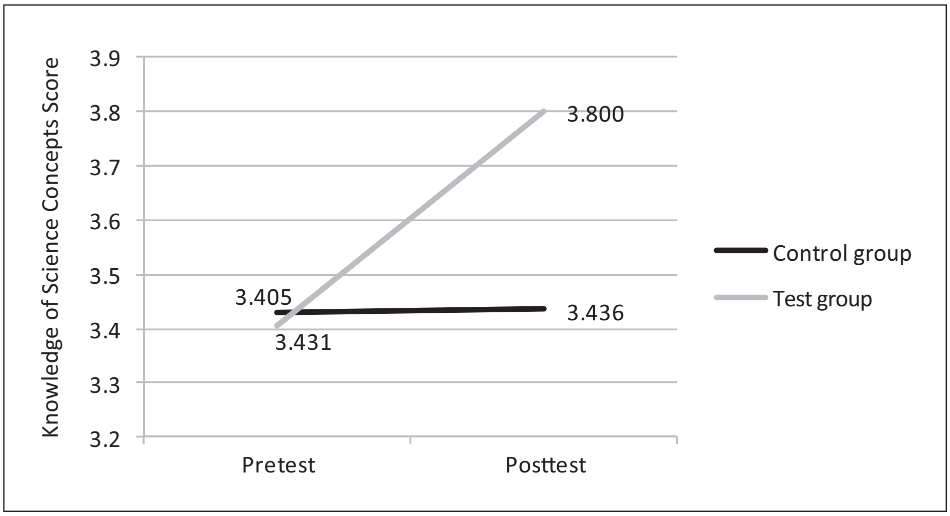


Figure 4 Gains in understanding of key science concepts after students were shown episodes of *Design Squad* in their middle school science classrooms. Source: Adapted from Concord Evaluation Group, 2010.

Finally, *Design Squad* was also found to be effective in formal school environments (Figure 4). Compared to a control group, children exposed to *Design Squad* in middle school science classrooms demonstrated significant gains in understanding key science concepts and showed improvement in their attitudes toward engineering (Concord Evaluation Group, 2010).

Future Research

EYL and *Design Squad* have shown that messaging can work. However, we still do not completely understand how messages interact with other contextual, social, and intra-personal factors to prompt young women into action (i.e., to enroll in an engineering program). We will need a deeper understanding of how messaging influences career decisions to significantly increase the participation of women and other underrepresented groups in engineering.

To that end, EYL, in collaboration with Clemson University and National Engineers Week Foundation (with support from Concord Evaluation Group), hopes to undertake a study to collect qualitative data about young women's career expectations and the factors that influence them. Knowledge gained from this study will have a direct impact on our understanding of how images and messages can awaken a young woman's interest and influence her career decisions. This knowledge will also help inform institutions of higher education about the potential role (positive or negative) of messages in college and university recruitment strategies.

To improve understanding of how seeds of engineering interest are sown, nurtured, and developed during a student's formative years, *Design Squad* hopes to conduct a study on informal pathways to engineering. Using social cognitive career theory, the study would show how informal engineering programs can sustain children's interest and participation in engineering and provide a more nuanced picture of the kinds of children most receptive to informal engineering education. The study would also have a larger goal—to provide a template for other informal engineering programs to assess students' reactions and to provide data for comparing results.

To maximize the impact of this study, WGBH, Concord Evaluation Group, and Purdue University have formed strategic partnerships with Project Lead the Way, Girl Scouts of the USA, National Engineers Week Foundation, National Girls Collaborative Project, FIRST, International Technology and Engineering Educators Association, and Association of Science-Technology Centers. These groups will weigh in on questions about the overall design of the study and review the test instruments to ensure that they are appropriate for middle-school children.

Once this study is completed, WGBH will encourage all partners in the study to use the resulting research tools in their own organizations to help determine which aspects of the informal engineering education system work best and how different parts of the system can work together more effectively.

Conclusion

Based on our work with EYL and *Design Squad*, we now understand that messaging can have a positive impact on children's attitudes. But to take the next step, we must learn how this can ultimately translate into changes in behavior, with the ultimate goal of smoothing the way from a student's initial awareness of engineering to his or her career as a professional engineer.

References

Concord Evaluation Group LLC. 2010. Evaluation of Design Squad, Season 3: Final Report. Concord, Mass.

EWE (Extraordinary Women Engineers Coalition). 2005. Final Report. Boston, Mass.: EWE.

Goodman Research Group Inc. 2008. Design Squad: Final Evaluation Report. Cambridge, Mass.

NAE (National Academy of Engineering). 2008. Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington, D.C.: National Academies Press.

NSB (National Science Board). 2010. Science and Engineering Indicators 2010. Arlington, Va.: National Science Foundation.

NSF (National Science Foundation). 2006. Science and Engineering Degrees: 1966–2004. Arlington, Va.: Division of Science Resources Statistics, NSF.

Veridian inSight. 2009. Engineer Your Life Evaluation Report for Year 2. Concord, Mass.

Veridian inSight and American Institutes for Research. 2009. Design Squad Season 2 Final Evaluation Report. Concord, Mass.

White House. 2009. Remarks by the President at the National Academy of Sciences Annual Meeting. Washington, D.C.: The White House.

NAE News and Notes

A Tribute to George Bugliarello

George Bugliarello

George Bugliarello slipped from our midst on February 18, 2011. George had slowed down some in the last few years as evidenced most by his adoption of a cane as an occasional assist. But he was such a delight to be around, and his intellectual enthusiasm for discussing all matters of science, engineering, technology, and society was so mesmerizing that one mostly didn't notice his physical challenges. He bounced back from a number of health ailments in recent years and, when he contracted a cold that progressed to pneumonia, the sense was that he would bounce back again. As he waited for antibiotics to do their job, he passed his time in the hospital working on an article for the March issue of *The Bridge*, for which he served as "interim editor in chief" for over a decade. But this time, recovery was not to be.

George was the Foreign Secretary of NAE from July 1, 2003, until his death. He was limited by the NAE Bylaws to two four-year terms, and as chance would have it, the wheels were already in motion to select a Foreign Secretary to replace him.

NAE is greatly indebted to George for his outstanding service in international affairs and his wise counsel on all facets of engineering and technology as a member of the NAE Council. His election as Foreign Secretary was a stroke of insight on the part of the NAE membership, because he brought enormous experience to the post based on many years of participation in both UN and National Research Council international study delegations. He led NAE interactions with the other engineering academies of the world, through the Council of Academies of Engineering and Technical Sciences, and supported and participated in our bilateral Frontiers of Engineering (FOE) symposia held with Germany, Japan, India, China, and the European Union. As one would expect of a person who was a lifelong educator, he was especially drawn to the young engineers invited by NAE to participate in FOE meetings.

George with foreign associate Kuangdi Xu, president, Chinese Academy of Engineering.

One of those young engineers, Melissa Knothe Tate, of Case Western Reserve University, was moved to write a remembrance of George:

> The loss of a mentor like George Bugliarello is devastating, but the fruits cultivated through his mentorship will continue to grow, nourish, and disperse new scientific seeds, sowing a bright future for engineering. George was a world citizen who never lost his curiosity to learn anew; perhaps his greatest legacy will be as a role model for mentoring talented young

George; Pam Lankowski, NAE Council Administrator; Virginia Bugliarello; William Colglazier, Executive Officer, NAS/NRC, and Chief Operating Officer, NRC; and Cathy Colglazier relaxing during a break during the 2007 NAE Council Meeting at Chairman Craig Barrett's Triple Creek Ranch in Darby, Montana.

George and Virginia Bugliarello with new Foreign Associate (2007) Kenichi Iga (now president, Tokyo Institute of Technology), and Mrs. Tomoko Iga.

engineers and for helping society to understand the great potential as well as societal implications of the technologies that we, as engineers, develop. At Frontiers meetings, together with other meeting participants, we engaged in discussions as diverse as cell mechanics, alternative energy technologies, engineering human health, and the history of engineering science. These discussions occurred at poster sessions, coffee breaks, bus rides, wherever George could get a discussion going; he was simply insatiable for knowledge! George had an uncanny way of seeing the "big picture," particularly with respect to engineering, technology, and society. I will never forget how eye opening it was to hear him speak of the technological developments exerting the greatest impact on society; of course he touched on obvious technological developments regarding energy and transportation, but perhaps more remarkably, he talked about the development of television, its impact on human interaction and its lasting transformation of society over the past decades. I had never thought of the impact of such ubiquitous entertainment "technology" in that way.

George in his office at NYU Poly, 2005. Courtesy of Polytechnic Institute of NYU.

George was revered by NAE members and foreign associates and many have sent notes of condolence to NAE. His legacy extends far, far beyond his service to NAE, and this legacy has been captured eloquently by others. Perhaps, George's persona was captured best by the description of NAE member **Bert Westwood**, who noted that he was a gentleman, a scholar, an outstanding engineer, dedicated member of our fraternity, a multicultural enthusiast, and an experienced and accomplished diplomat in the cause of international understanding and scientific collaboration.

Charles M. Vest

Lance A. Davis

NAE Newsmakers

Norman R. Augustine, retired chairman and CEO, Lockheed Martin Corporation, has been selected the **2011 Engineering Leader of the Year** by the Drexel University College of Engineering. Mr. Augustine received the award on February 15, 2011.

Arden L. Bement Jr., former director of the National Science Foundation and director, Global Policy Research Institute, Purdue University, was named a **Chevalier dans l'Ordre National de la Legion d'Honneur** (officer of the French Legion of Honor). Dr. Bement received the award on March 24 at the residence of the ambassador of France in Washington, D.C. Created by Napoleon Bonaparte in 1802, this prestigious award is given in recognition of military, cultural, scientific, and social contributions to France.

Jay Boris, chief scientist and director, Laboratory for Computational Physics and Fluid Dynamics, U.S. Naval Research Laboratory (NRL), was awarded the **Timothy P. Coffey Innovation Award** in recognition of innovations that have improved the accuracy and speed of 3D predictions by CT-Analyst® (a software tool) of chemical, biological, and radiological agent transport in urban settings. The award, named after NRL's fifth director of research, was established to recognize key developers of exceptional scientific and technological innovations that have had (or could potentially have) major impacts on science and technology, U.S. naval forces, and/or national security.

Joseph M. DeSimone, W.R. Kenan Jr. Distinguished Professor of Chemistry and Chemical Engineering, Department of Chemistry, University of North Carolina at Chapel Hill, has received the **2010 Mentor Award** from the American Association for the Advancement of Science (AAAS). The award is bestowed on association members who have mentored significant numbers of students in underrepresented groups—such as women, minorities, and persons with disabilities—working toward Ph.D.s in the sciences. Dr. DeSimone, who has served as mentor to nine African-American students, one Hispanic-American student, and 24 women who have now earned Ph.D.s in chemistry, was recognized for advancing diversity among doctoral-level chemists entering the workforce. He received the award on February 19, 2011, at a ceremony during the association's annual meeting in Washington, D.C.

Odd Magnus Faltinsen, professor of marine technology, Norwegian University of Science and Technology, received the **Fridtjof Nansen Award** for outstanding research in science and medicine on May 3 at the Annual Meeting of the Norwegian Academy of Science and Letters. Dr. Faltinsen was recognized for his theoretical and numerical methods of understanding how ships, high-speed vehicles, and offshore structures behave in waves, and the sloshing dynamics of liquids aboard ships.

The Association for Computing Machinery (ACM) has chosen **M. Frans Kaashoek**, professor, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, as the recipient of the **2010 ACM-Infosys Foundation Award in the Computing Sciences**. Dr. Kaashoek was honored for contributions to the structuring, robustness, scalability, and security of software systems that have led to more efficient, portable, highly distributed applications of software systems and enabled wider use of portable embedded and distributed systems; he also used information flow-control techniques to address a major security challenge in commercial systems. In addition, Dr. Kaashoek founded commercial ventures that have (1) enabled wider distribution of content, such as large, high-quality video files that can travel over the Internet and (2) improved the protection of large enterprise networks using network behavioral analysis software. The ACM-Infosys Foundation Award, established in 2007, is given for major innovations by young scientists and system developers. Financial support for the $150,000 award is provided by an endowment from the Infosys Foundation.

The Association for Computing Machinery (ACM) has named **Takeo Kanade**, U.A. and Helen Whitaker University Professor of Computer Science and Robotics, Carnegie Mellon University, the 2010 winner of the **ACM/AAAI Allen Newell Award** for contributions to research in computer vision and robotics. The Newell Award, named for a founding father of the Carnegie Mellon School of Computer Science, recognizes career contributions that have had a widespread impact on computer science or that bridge computer science and other disciplines. The $10,000 prize is supported by the Association for the Advancement of Artificial Intelligence (AAAI) and individual contributors. The award was presented June 4 at the ACM Awards Banquet in San Jose, California.

Simon Ramo, co-founder, TRW Inc., is the recipient of the **Robert H. Goddard Memorial Trophy**, the preeminent award of the National Space Club. The Goddard Memorial Trophy is given in recognition of significant contributions to U.S. leadership in rocketry and astronautics. Dr. Ramo was cited for his "lifetime of engineering and scientific leadership and achievement that has made an unparalleled impact on our nation's space programs." Among his many accomplishments are his critical role in early space programs, including intercontinental ballistic missiles, the Thor, Atlas, and Titan rockets, Project Mercury, Pioneer 1, VIKING 1 and 2, and the Lunar Excursion Model Descent Engine. The award ceremony was held on April 1, 2011, in Washington, D.C.

Dennis Ritchie, member of the Technical Staff, and **Kenneth Thompson**, retired member of the Technical Staff, Bell Laboratories, Lucent Technologies, were awarded the **2011 Japan Prize** in information and communications. The Japan Prize is awarded annually to scientists and researchers who have made substantial contributions to science and technology and to the world. Drs. Ritchie and Thompson were chosen for developing the UNIX operating system and the C programming language for use on UNIX, thus significantly advancing computer software, hardware, and networks over the past four decades and facilitating the realization of the Internet. The winners received certificates of recognition and commemorative gold medals at an awards ceremony on April 20, 2011, during Japan Prize Week in Tokyo.

Bruce E. Rittmann, Regents Professor of Environmental Engineering, and director, Center for Environmental Biotechnology, Biodesign Institute, Arizona State University, has received the prestigious **Environmental Engineering Excellence Award** from the American Association of Environmental Engineers. Dr. Rittmann was honored for winning the Excellence in Environmental Engineering Competition for the development of the hydrogen-based membrane biofilm reactor (MBfR) that removes contaminants from water, such as nitrate, perchlorate, selenate, chromate, and trichloroethene. The criteria for the award were: a holistic environmental perspective; innovation; proven performance and customer satisfaction; and contributions to quality of life and economic efficiency. The award was presented to Dr. Rittmann on May 4, 2011, at the National Press Club in Washington, D.C.

Esther S. Takeuchi, SUNY Distinguished Professor and Greatbatch Professor of Advanced Power Sources, University at Buffalo, will be one of nine living inductees into the **National Inventors Hall of Fame**, which honors inventors whose innovations have changed the world. At last count, Dr. Takeuchi had earned 148 patents (more than any other woman in the United States), mostly related to her pioneering development of sophisticated power sources for implantable devices.

David A. Tirrell, professor, California Institute of Technology, received the Carnegie Mellon University **2010 Dickson Prize in Science**. This prestigious prize, established in 1969 by the late Pittsburgh physician Joseph Z. Dickson and his wife Agnes Fisher Dickson, is awarded annually to individuals in the United States who make outstanding contributions to science. Dr. Tirrell received the award, which includes a medal and a cash prize, on March 21, 2011.

Paul E. Torgersen, John W. Hancock Jr. Chair and President Emeritus, Virginia Polytechnic Institute and State University, was awarded the **2010 Industrial and Systems Engineering Distinguished Alumni Award for Achievements in Academia** by Lehigh University.

Moshe Y. Vardi, George Professor in Computational Engineering, Department of Computer Science, Rice University, has been named the winner of the Institute of Electrical and Electronics Engineers (IEEE) Computer Society's **2011 Harry H. Goode Award**. The Goode Award was established to recognize achievements in information processing—either an outstanding single contribution to theory, design, or technique or an accumulation of important contributions to theory or practice over an extended period of time. Dr. Vardi was honored for his "fundamental and lasting contributions to the development of logic as a unifying foundational framework and a tool for modeling computational systems."

Charles M. Vest, president, National Academy of Engineering, and President Emeritus and professor, mechanical engineering, Massachusetts Institute of Technology, will receive the **2011 Vannevar Bush Award** from the National Science Board (NSB) for distinguished public service and leadership in science and technology. Every year, NSB presents the Vannevar Bush Award to an individual who, through public service in science and technology, has made an outstanding "contribution toward the welfare of mankind and the nation."

Amnon Yariv, Martin and Eileen Summerfield Professor of Applied Physics and professor of electrical engineering, California Institute of Technology, is the recipient of the **2011 IEEE Photonics Award**. The award was presented on May 4 "For fundamental contributions to photonics science, engineering and education that have broadly impacted quantum electronics and lightwave communications."

On May 3, six NAE members were elected to the National Academy of Sciences during its Annual Meeting: **Ted B. Belytschko**, Walter P. Murphy and McCormick Institute Professor, Department of Mechanical Engineering, Northwestern University, Evanston, Illinois; **James W. Demmel**, Dr. Richard Carl Dehmel Distinguished Professor of Mathematics and Computer Science, Department of Mathematics and the Computer Science Division, University of California, Berkeley; **Jon M. Kleinberg**, Tisch University Professor, Department of Computer Science, Cornell University, Ithaca, New York; **Leslie B. Lamport**, principal researcher, Microsoft Research, Mountain View, California; **Parviz Moin**, Franklin P. and Caroline M. Johnson Professor of Engineering, Department of Mechanical Engineering, Stanford University, Stanford, California; and **H. Vincent Poor**, dean of engineering and applied science and Michael Henry Strater University Professor of Electrical Engineering, Princeton University, Princeton, New Jersey.

NAE Honors 2011 Prize Winners

Every year NAE honors outstanding individuals for significant innovation, leadership, and advances in bioengineering. The 2011 award winners were honored at an elegant dinner on February 22 at historic Union Station in Washington, D.C. The recipients of the Charles Stark Draper Prize, Fritz J. and Dolores H. Russ Prize, and Bernard M. Gordon Prize accepted their awards before an audience of more than 300 guests, with NAE President **Charles M. Vest** and NAE Council Chair **Irwin M. Jacobs** at the podium. Presenters at this year's ceremony were James D. Shields, president and CEO, Charles Stark Draper Laboratory Inc., Roderick J. McDavis, president, Ohio University, and Harold S. Goldberg, advisor to the Gordon Prize Committee.

Charles Stark Draper Prize

James D. Shields, president and CEO, The Charles Stark Draper Laboratory Inc.; Irwin M. Jacobs; Willem P.C. "Pim" Stemmer, founder and CEO, Amunix Inc., and Frances H. Arnold, Dick and Barbara Dickinson Professor of Chemical Engineering and Biochemistry, California Institute of Technology, recipients of the Draper Prize; and Charles M. Vest. Photo by Event Digital Photography Inc.

Frances H. Arnold and **Willem P.C. "Pim" Stemmer** were awarded the 2011 Charles Stark Draper Prize "for directed evolution, a method used worldwide for engineering novel enzymes and biocatalytic processes for pharmaceutical and chemical products."

The principal at the heart of directed evolution is that natural mutation and selection processes can be vastly accelerated in the laboratory to obtain specific, targeted improvements in the function of single proteins and multi-protein pathways. Frances Arnold showed that randomly mutating genes of a targeted protein, especially enzymes, would result in proteins with more desirable traits. She then selected the most desirable of the new proteins and repeated the process many times, essentially directing their evolution until they had attained the properties desirable for a particular use.

Taking his cues from classical breeding methods of plants and animals, Willem Stemmer focused on a natural process for creating diversity, which he called "DNA shuffling." Instead of allowing random mutations, he shuffled the same gene from diverse but related species to create clones with a given targeted property that was as good as, or better than, the same property in the parent genes.

Thus directed evolution is a practical, cost-effective way of improving protein function. Previous efforts, particularly if they were based on the structures of enzymes and the predicted effects of mutations, were often unsuccessful. They not only failed to improve the sought-after complex combinations of properties, but they were also labor- and cost-intensive.

Today, the techniques of directed evolution developed by Arnold and Stemmer—and several variants—are widely used in engineering, chemistry, and biochemistry, for example in food science, pharmaceuticals, toxicology, agricultural products, gene delivery systems, laundry aids, and biofuels.

Frances H. Arnold is the Dick and Barbara Dickinson Professor of Chemical Engineering, Biochemistry, and Bioengineering at the California Institute of Technology. Dr.

Arnold received a B.S. in mechanical and aerospace engineering from Princeton University in 1979 and a Ph.D. in chemical engineering from the University of California at Berkeley in 1985. She is listed as co-inventor on more than 30 U.S. patents and has served as science advisor to more than 10 companies, including Maxygen, Amyris, Codexis, Mascoma, and Gevo Inc., a company she co-founded in 2005 that develops new microbial routes to producing fuels and chemicals from renewable resources. She has received numerous academic awards and is one of only seven individuals who are members the National Academy of Engineering (2000), Institute of Medicine in (2004), and National Academy of Sciences (2008).

Willem P.C. "Pim" Stemmer is founder and CEO of Amunix Inc., Mountain View, California, a company that creates pharmaceutical proteins with extended dosing frequency. Amunix products comprise a clinically proven pharmaceutical payload, typically a human protein, genetically fused to XTEN, a long, unstructured, hydrophilic protein chain. Like polyethylene glycol, XTEN increases serum half-life by increasing the hydrodynamic radius, thus reducing kidney filtration. In 2008, Amunix joined with Index Ventures to create Versartis Inc. for the purpose of clinical development of three specific products for the treatment of metabolic diseases.

Pim Stemmer has also invented other technologies that have led to the creation of successful companies and products. In 1993, he invented DNA shuffling (described above), which became known as molecular breeding, and in 1997, he co-founded Maxygen to commercialize the process. His portfolio of patents from Maxygen was consistently ranked in the top five Pharma/Biotech portfolios by MIT's *Technology Review* and the *Wall Street Journal Patent Scorecard*. Prior to 1993, he was a Distinguished Scientist at Affymax and a scientist at Hybritech working on antibody-fragment engineering for the treatment of colon cancer. In 2001, he invented the Avimer technology, and in 2003, he founded Avidia to commercialize it; he was chief scientific officer of the company until 2005.

Dr. Stemmer has 68 research publications and 97 U.S. patents to his credit and has given more than 300 invited lectures. He is a recipient of the Doisy Award, the Perlman Award, and the NASDAQ VCynic Award.

Dr. Stemmer received his Ph.D. from the University of Wisconsin-Madison in 1985 for his work on bacterial pili/fimbriae and other virulence factors involved in host-pathogen interaction. He completed his postdoctoral work with Professor Fred Blattner at the University of Wisconsin-Madison on phage display of random peptide libraries and antibody-fragment expression in *E. coli*.

Acceptance Remarks by Frances H. Arnold

Frances H. Arnold, co-recipient of the Charles Stark Draper Prize. Photo by Event Digital Photography Inc.

I am honored to be standing here where previous innovators who have won the Draper Prize were recognized. It is humbling to be part of this distinguished group. I want to thank the Draper Laboratory and all of you from the National Academy of Engineering who participated and saw fit to award this prize to me and Pim.

Earlier today, when I was speaking to sixth, seventh, and eighth graders, I was asked what had inspired me to work on directing evolution. I thought about that question and realized that my inspiration had come from three very different places. It came from engineering—the desire to solve real problems through science and technology. It also came from desperation—not knowing how to do that, because when I started evolving proteins more than 20 years ago, we didn't know how to build biological molecules that would be useful. But most of all, my inspiration came from a great engineering role model—Nature.

If we want a world where technology helps us live sustainably, a world where our children have a standard of living that even approximates the one we have been lucky enough to have, then we must look to the very best engineers. And I can tell you with great confidence that Nature is the best engineer.

Nature has discovered absolutely amazing solutions to an incredible array of difficult problems. Nature has figured out how to extract materials and energy from widely different environments and convert them to a vast collection of brilliant materials and organisms. And Nature has done this with great efficiency and often minimal waste.

Since the beginning of my career as a biological engineer, my inspiration has come from Nature. I wanted to use Nature to solve human problems, but getting Nature to solve problems for us is a challenge. The code of life is as intricate and stunningly beautiful as a Beethoven symphony. As much as we might love to sit down at our pianos—or computers—and write music like that, we can't. We simply don't understand the principles of how DNA encodes life. We are not ready to engineer biology, or even biological molecules like enzymes, from first principles.

As we well know, engineers have never been required to design anything from first principles. We build things using what we have, and ignorance of the underlying physics or chemistry can be circumvented by creativity and experimentation. Thus I never felt I had to sit down and design, from my limited understanding and experience, new biological molecules. I just said, "Let's try a process that we know works." That process is evolution.

About three and a half billion years ago, Nature figured out how to build new catalysts, new materials, new organisms by a process as elegant as it is simple. (An engineering lesson I learned early on: keep it simple.) Evolution builds the most beautiful, and functional, biological objects, and if we want to build new ones that can convert renewable resources into fuels and chemicals or cure diseases, we can do it by that same process. Pim and I discovered what Nature discovered at the beginning of life—evolution is the best possible design algorithm for biology. Blind is better.

I want to thank my colleagues who are here tonight, especially those who supported me when it wasn't clear that my ideas would work—it's always risky to try something new. I have had wonderful colleagues and supporters at the California Institute of Technology, and I am very grateful to have Caltech as a place where I can play with new ideas.

I also want to thank my friends who have helped me during the last few years—their support has meant a great deal to me. And I thank my current and former students, especially those who were willing to join a young professor's group to work on something as out-there as directing evolution in the laboratory.

Finally, I thank my family. My sons William Andrew Lange and Joseph Inman Lange are here with me tonight. My oldest son, James Bailey, is serving overseas in the armed forces and was not able to come. Most of all, I thank my father, who always told me that even though I could do anything, I should become an engineer because I would always have a good job. It was very good advice.

Acceptance Remarks by Willem P.C. "Pim" Stemmer

William P.C. "Pim" Stemmer, co-recipient of the Charles Stark Draper Prize. Photo by Event Digital Photography Inc.

I would like to thank Frances Arnold and the Diversity Biotechnology Consortium for stimulating interactions. I also thank Andreas Crameri for performing many early experiments. And I thank the companies Maxygen, Codexis, Verdia, and Altravax for the continued development of molecular breeding technology.

When Frances and I started our work, everyone was convinced that in the future proteins would be designed by computer modeling. In 1985, upon completion of my Ph.D., I started a company, with funding from a university-industry research grant, to focus on protein design by functional selection of proteins from large protein libraries.

The initial processes Frances and I used required screening thousands of clones for many cycles to get improvement. About 10 years later, by optimizing the technology, we had much improved those processes, and the best of them required screening only a hundred or so clones for one or maybe two cycles. The improved process involved using homologous recombination to permutate natural diversity and to go from cycle to cycle. Once we had developed this process for single genes, mostly enzymes, it was adapted, using different techniques but the same concept, to multi-gene pathways, distributed multi-gene pathways, and whole genomes.

We were also excited about the application of molecular breeding to whole microbial communities, which remains to be demonstrated. But I think of it as a molecular supercomputer for the design of novel pathways and organisms.

All along the way, my guiding light was the process of dog breeding. In dog breeding, homologous recombination (especially when mating different breeds) produces puppies that differ by tens of thousands of point mutations from each other and from their parents. Although the puppies are generally as fit as the parents, they differ from them in many properties, such as fur color. We know that selection from 10 puppies for a few generations can take us anywhere in dog space.

The point is that this seemingly complex design process can be directed by a child, and the reason dog breeding works so well is that natural diversity is very conservative. The question is how we can mimic this process in molecular biology and control many more variables but essentially perform the same process for all kinds of sequences.

The principles we learned from our work are that rules for engineering very complex systems are different and that we must use molecular computation instead of computer simulation. We learned that we have to optimize many variables simultaneously, but conservatively, using natural diversity. We learned that increasing the complexity of a system, by adding conjugative plasmids and other tools for genetic exchange, creates more ways to succeed. We learned to include available rational information opportunistically in the libraries, so that many different hypotheses could be evaluated simultaneously. We learned that it is very important to use predictive screens that closely mimic the conditions of the final application and that these conditions have to be used early in the screening process.

Finally, I hope that better simulation of directed evolution, including the use of natural diversity, will revitalize the field of genetic algorithms and eventually make the directed evolution of non-biological sequences possible.

Fritz J. and Dolores H. Russ Prize

Roderick J. McDavis, president, Ohio University; Irwin Jacobs; Leroy E. Hood, president, Institute for Systems Biology, and recipient of the 2011 Russ Prize; and Charles M. Vest. Photo by Event Digital Photography Inc.

The recipient of the 2011 Fritz J. and Dolores H. Russ Prize, a $500,000 award given in recognition of a bioengineering achievement that has improved the human condition, is Leroy E. Hood. Dr. Hood was cited for automating DNA sequencing, which revolutionized biomedicine and forensic science.

Dr. Hood received an M.D. from Johns Hopkins University and a Ph.D. from California Institute of Technology, where he was a faculty member for 22 years. His research initially focused on fundamental biology (immunity, evolution, genomics, and neurobiology) and on bringing engineering and biology together through the development of five instruments—a DNA sequencer, a DNA synthesizer, a protein sequencer, a peptide synthesizer, and an ink-jet printer for DNA arrays—all of which have since been commercialized (Applied Biosystems and Agilent).

In the 1980s, Dr. Hood began to focus more on cross-disciplinary biology and systems biology. In 1992, with support from **Bill Gates**, he moved to the University of Washington, where he was the founder and chairman of the Molecular Biotechnology Department (the first cross-disciplinary biology department). In 2000, he co-founded, and is still president of, the Institute for Systems Biology in Seattle, Washington, an independent, nonprofit organization that develops strategies and technologies for systems approaches to biology and medicine. Dr. Hood is currently working on transitioning medical care from a reactive to a proactive (P4) approach based on predictive, preventive, personalized, and participatory care of individual patients and systems approaches to diagnostics and therapeutics. He is also working on the development of clinical assays for exploring new dimensions of the patient data space.

Dr. Hood was awarded the Lasker Prize in 1987 for studies of the mechanism of immune diversity; the 2002 Kyoto Prize in Advanced Technology for development of automated technologies for analyzing proteins and genes; the 2003 Lemelson–MIT Prize for Innovation and Invention for the development of the DNA sequencer; the 2006 Heinz Award in Technology, the Economy and Employment for breakthroughs in biomedical science on the genetic level; membership in the 2007 Inventors Hall of Fame for the automated DNA sequencer; the 2008 Pittcon Heritage Award for helping to transform the biotechnology industry; and the 2010 Kistler Award for contributions to genetics that have benefitted mankind.

Dr. Hood has received 17 honorary degrees from institutions, including Johns Hopkins, Yale, and UCLA, and has published more than 700 peer-reviewed papers, received 22 patents, and co-authored textbooks in biochemistry, immunology, molecular biology, and genetics. In addition, he co-authored, with Dan Keveles, *The Code of Codes: Scientific and Social Issues in the Human Genome Project* (Harvard University Press, 1992), a popular book on the sequencing of the human genome.

Dr. Hood is a member of the American Philosophical Society and the American Association of Arts and Sciences, as well as the National Academy of Sciences (NAS), Institute of Medicine, and National Academy of Engineering. Indeed, he is one of only seven individuals (of more than 6,000 members of The National Academies) who has been elected to all three academies. Dr. Hood has been instrumental in founding 13 biotechnology companies, including Amgen, Applied Biosystems, Systemix, Darwin, Rosetta, Integrated Diagnostics, and the Accelerator.

Acceptance Remarks by Leroy E. Hood

Leroy E. Hood, president, Institute for Systems Biology, and recipient of the 2011 Russ Prize. Photo by Event Digital Photography Inc.

Receiving the Russ Prize is a wonderful honor. I would like to thank the Russ family who created the prize; Ohio University, which sponsors the prize; the National Academy of Engineering, which manages the prize; the Russ Selection Committee; and last, but not least, my colleagues who have made it possible over the years for me to win the prize.

One of my joys has been to participate in a number of paradigm shifts in biology over the course of my career, that is, changes in how we think about and practice biology. I will talk about five of these changes, how the first led naturally to the second and how the first four were essential to the fifth. The five paradigm shifts are: bringing engineering to biology; the Human Genome Project; cross-disciplinary biology; systems biology; and P4 medicine.

Bringing Engineering to Biology

The first paradigm shift was bringing engineering to biology. In 1970, when I came to Caltech as a young assistant professor, I decided I would spend half my time trying to develop technologies for deciphering molecular biological information—DNA, RNA and proteins. I spent the other half doing molecular immunology. Over the next 25 years or so, my colleagues and I developed a series of five instruments that created platforms for modern biological analyses—deciphering the mysteries of DNA, RNA, and proteins.

What was instructive in developing the automated DNA sequencer was our initial failure. I had persuaded an excellent biologist to undertake this task, but over a three-year period, he failed because he did not have sufficient command of four key disciplines—molecular biology, chemistry, engineering, and computer science—whose integration was necessary for automating DNA sequencing.

I then assembled a team of four scientists who rapidly solved the problem. Lloyd Smith, an outstanding chemist and laser specialist, **Mike Hunkapiller**, an engineering genius with superb instrumentation skills, Tim Hunkapiller, a biologist/computer scientist, and I rethought the problem and within six weeks, had conceived the concept of four-color DNA sequencing (a different color for each of DNA base).

I founded Applied Biosystems Inc. in 1981 to commercialize the first four instruments my lab developed (DNA and protein sequencers and synthesizers). Lloyd Smith pioneered the development of the first prototype instrument, which emerged in 1985. By the late 1980s the biological community could purchase robust, easy-to-use, automated DNA sequencers.

The development of the automated DNA sequencer gave me a deep appreciation for the power of cross-disciplinary approaches to biological problems, which led directly to the second paradigm change—the Human Genome Project.

The Human Genome Project

Initially proposed in 1984, the Human Genome Project was about determining the order of DNA letters in the 23 pairs of human chromosomes (e.g., the genome or the source code for creating humans). Using the sequencing technology available at the time, this task might well have taken 100 years. Because of my interest in automated DNA sequencing, I was invited, with 11 other "experts," to the first meeting on the Human Genome Project at Santa Cruz in May 1985. The group decided that the genome project was feasible, although it would be technically difficult. Several of us spent the next five years convincing a very skeptical community of biologists that the genome project could transform biology.

I played an active part in the Human Genome Project: (1) my team developed the automated DNA sequencer that enabled the project; (2) I was an early advocate for the project when 90 percent of biologists were initially opposed (the National Institutes of Health [NIH] aggressively opposed it up until the final decision was made to go forward); (3) I was on the National Academy of Sciences committee that generated a favorable report in 1988-1989, which led to the initiation of the proposed 15-year project in 1990; and (4) I directed a Human Genome Sequencing Center that sequenced portions of chromosomes 14 and 15. This was one of 16 such centers in the United States.

The most remarkable thing about the Human Genome Project is that it demonstrated explicitly how the needs of biology can lead to transformational new technologies that, in turn, can revolutionize biology—and catalyze the emergence of remarkably different aspects of biology.

A narrowly focused article by Nicholas Wade in the *New York Times* in 2010 purported to show how the Human Genome Project had failed to live up to its promise. The article stimulated my thinking about the transcendent benefits the project had yielded, which are remarkably broad in scope. Let me cite briefly 14 accomplishments that revolutionized both biology and medicine.

First, the Human Genome Project democratized genes, that is, made all genes accessible to all biologists.

Second, it delineated, for the first time, all human genes and, by inference, all proteins. This comprehensive "parts list" enabled a new approach to biology that I called "systems biology"—a holistic approach to dealing with biological complexity. The concept of systems biology is the focus of the work done at my Institute for Systems Biology—the first systems biology organization—started in 2000.

Third, the Human Genome Project catalyzed the development of high-throughput instrumentation, the very effective generation of biological information in genomics, proteomics (the study of proteins), metabolomics (the study of small molecules), and phenotypic assays.

Fourth, it pioneered the applications of computer science and mathematics to biology. In fact, the genome project legitimately brought mathematicians and computer scientists, and even theoretical physicists, into biology to think about acquiring and storing, analyzing, mining, integrating, and ultimately creating predictive and actionable models of complex biological systems.

Fifth, it was the first biological project with an open source policy for all data. It mandated the instantaneous release of data to the biological community so everyone could analyze the new information immediately as it was produced.

Sixth, it created the first rigorous standards for biological data—and project funding depended on meeting these standards.

Seventh, it gave us access to the genomes of plants, animals, and microbes, and knowledge of those genomes has transformed many fields of biology.

Eighth, it revolutionized our understanding of evolution in absolutely magnificent ways.

Ninth, it transformed how we think about medicine. It created a new field of medical diagnostics using biomarkers in tissues and blood, which can actually detect disease early and stratify complex diseases into subtypes, making it possible for physicians to do impedance matches against appropriate therapies.

Tenth, it opened up the possibility of using DNA sequencing to identify genes that have actionable behaviors with regard to patients. For example, Leiden factor 5, a gene defect, leads to an increased tendency for blood clotting. A patient with this defect should drink lots of water, should not sit on an airplane for five hours without walking and stretching, and may take low doses of anticoagulants. This knowledge is particularly important for pregnant women with the defective gene.

Eleventh, physicians now use DNA sequencing of tumors to analyze disease-perturbed biological networks to determine the right drug for individual patients.

Twelfth, the genome project created a scientific environment, which, in part, led to the fifth paradigm change, P4 Medicine, which I will discuss shortly.

Thirteenth, the genome project changed the sociology of biology. For example, it introduced the concept of "big science" to biology. By big science I mean cross disciplinary, hypothesis-driven science that integrates different data types to build predictive models to help solve difficult problems, such as P4 Medicine. "Small science" is done by a single investigator and a few co-workers and takes on highly focused, discrete problems.

The synergy between big and small science is enormous. Each can take advantage of the strengths of the other, and they can effectively operate in an integrated way. Unfortunately, at NIH today, there is a tendency—driven by budget constraints and supported by many scientists who practice small science—to do away with big science. However, eliminating big science would be a tragic mistake, because we need it to take on complex and challenging problems of biology and society. We obviously need a mixed portfolio that will enable us to take advantage of the strengths of both big and small science in an integrated way.

Finally, the genome project was the first project that supported an investigation of the social, ethical, and legal aspects of the genome sequence in a way that *presaged* how we must consider medicine in the future.

Cross-Disciplinary Biology

The development of the automated DNA sequencer gave me a deep appreciation for the power of using cross-disciplinary approaches to address biological problems. Indeed, in 1992 with the help of **Bill Gates**, I moved from Caltech to the University of Washington Medical School to create the Department of Molecular Biotechnology, the first cross-disciplinary biology department. That department had a remarkable record of accomplishment: it pioneered the field of proteomics (the study of proteins); provided the software for data quality and the assembly of DNA sequence fragments for the Human Genome Project; developed the ink-jet DNA array synthesizer (the fifth instrument I developed); developed a novel, very high speed, multiparameter cell sorter; and housed two of the 16 U.S. genome centers.

In the 1980s, I had become convinced that immunology, my area of biological study, was far too complex to be studied in an atomistic way—one gene and one protein at a time. I realized we needed a holistic approach that could analyze how all genes (or proteins) behaved in this complex biological system. After we invented the tools for global analyses of genomic data, the genome project had generated a parts list of human genes and proteins, and we had created a cross-disciplinary environment in the Department of Molecular Biotechnology. It was time to create a new discipline I called systems biology.

Systems Biology

In 2000, I resigned from the University of Washington to co-found, with Alan Aderem and Ruedi Aebersold, the Institute of Systems Biology (ISB), the first of its kind in Seattle or anywhere. I did this because I found the bureaucratic constraints of the university to be at odds with the new organizational structure required for systems biology. A fascinating question is how old organizations can adapt to new paradigms. This is not easy—it requires leadership, flexibility, and a willingness to “change the rules.”

From ISB’s very inception, we began exploring a systems approach to disease, which requires integrating our cross-disciplinary environment. We pioneered new analytic tools and then used them to deal with enormous amounts of patient data.

P4 Medicine

The integration of these developments led to what I called P4 Medicine, a revolutionary new medicine that is predictive, personalized, preventive, and participatory. P4 Medicine embodies the idea that medicine is an informational science.

My 10-year vision for P4 Medicine is that a virtual cloud of billions of data points will surround each patient and that we will have computational tools to reduce that enormous data dimensionality to simple hypotheses about health and disease and to sculpt these phenomena, with exquisite specificity, for each individual. In so doing, P4 Medicine will: (1) demystify the complexities of disease and lead to better diagnoses and therapies; and (2) create metrics for assessing the wellness of each individual and optimize his or her future wellness.

P4 Medicine will have four implications for society. First, over the next 10 years it will force every sector of the health care industrial spectrum to reformulate its business plans and will thus create enormous potential economic opportunities for new and existing companies.

Second, it will lead to digitization of medicine, which will have three aspects: (1) analyses of billions of digital data points for each individual will provide enormous insights into health and wellness; (2) analyses of some single molecules, single cells, indeed of any quantized unit of information in humans, will lead to actionable information for the patient; and (3) wireless iPod®-style health devices with unobtrusive sensors will enable each individual to observe and record in real time understandable summaries of his or her personal data relevant to wellness and disease and to observe how these data change in response to environmental factors and lifestyle decisions. When combined with social networking tools and strategies, real-time access to personalized health data has the potential to engage patients in wellness-optimizing behavior modifications in a way that has never before been possible. The digitization of medicine will catalyze transformations in health care comparable to the changes emerging from the digitization of information technologies and communications.

Third, P4 Medicine will turn around the escalating costs of health care and bring them down to a point that will essentially solve the fiscal crisis presently faced by the United

States, which is caused in substantial part by rising health care costs. Moreover, we will be able to export P4 Medicine to the developing world, with the potential for democratizing health care, which was unimaginable even a few years ago.

Fourth, P4 medicine will create wealth for the countries in which it is practiced. This wealth will result from the enormous savings from effectively practicing wellness (and reducing the massive loss of profits due to sickness). In addition, the economic opportunities from a "wellness industry" will soon emerge, as part of the P4-catalyzed transformation of the conventional health care industry. Indeed, I forecast that, in time, the magnitude of this new wellness industry will far surpass that of the "disease industry," that is, the health care industry of today.

The acceptance of P4 Medicine into the mainstream of health care will require meeting two challenges: technical and societal. The societal challenge is to create legal, ethical, commercial, and policy structures that will enable the emergence of the radically disruptive P4 Medicine paradigm, which will change the focus of our health care system from reactive to proactive.

This societal challenge will be far more difficult to surmount than the technological challenge. Indeed, we recently established a nonprofit institute—the P4 Medicine Institute—to bring P4 Medicine to patients and begin dealing with selected societal problems. We believe small pilot projects will be essential to demonstrating the power of P4 Medicine, and we have initiated two with Ohio State University Medical School—one on wellness and one on heart failure.

Clearly, the first four paradigm changes described above were essential for the emergence of the fifth paradigm change—P4 Medicine. A wonderful question to contemplate is what the paradigm changes of the future will be and how they will build on the paradigm changes of the past.

In closing, let me thank one more person, my wife, Valerie Logan. Her unwavering support has been an essential cornerstone of my challenging career. One fascinating aspect of the approach my institute—the Institute for Systems Biology—has taken to tackling some "big problems" in biology (e.g., P4 Medicine) has been to create international strategic partnerships that bring together complementary skills, excellence, and new funding opportunities. I have to say, however, that of all the successful strategic partnerships in which I have participated, the partnership with Valerie Logan has been by far the best—and the whole has far exceeded the sum of its parts. Thank you, Valerie.

Bernard M. Gordon Prize

Harold S. Goldberg, advisor to the Gordon Prize Committee; Irwin Jacobs; Edward F. Crawley, professor of aeronautics and astronautics, Massachusetts Institute of Technology, and recipient of the Gordon Prize; and Charles M. Vest. Photo by Event Digital Photography Inc.

The Bernard M. Gordon Prize for Innovation in Engineering and Technology Education was awarded to Edward F. Crawley for leadership, creativity, and energy in defining and guiding the CDIO (Conceive-Design-Implement-Operate) Initiative, which has been widely adopted internationally for engineering education.

The CDIO Initiative places the traditional engineering curriculum in the context of problem-solving exercises and hands-on assignments, taking students out of theoretical classroom discussions to create experiences based on the needs of engineering in the 21st century. CDIO has been praised by industry for developing more well-rounded graduates with a foundation in teamwork, problem solving, and product development.

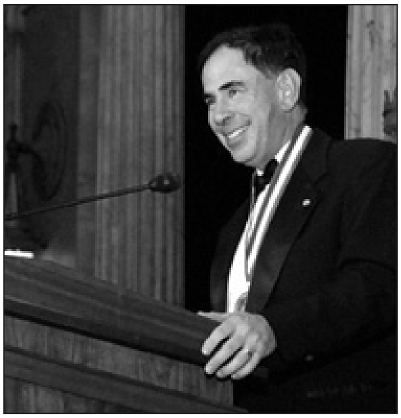
Designed to be widely disseminated and shared, a feature of CDIO is that it uses an "open architecture" model, allowing it to be modified and adapted to a particular university's needs. Schools that are part of the Initiative openly collaborate, sharing best practices and materials, and the Initiative has international reach, with more than 50 universities in 25 countries participating. The initiative holds an annual international conference and workshops throughout the year, bringing together current and potential collaborators.

To ensure uniformity, CDIO outlines 12 standards to be used as a tool for program adoption, evaluation, and continuous improvement. In addition, the initiative provides a detailed syllabus to provide a roadmap and process for establishing a program.

Edward F. Crawley is the Ford Professor of Engineering at Massachusetts Institute of Technology (MIT) and is a professor of aeronautics and astronautics and of engineering systems. He received an S.B. (1976), an S.M. (1978) in aeronautics and astronautics, and an Sc.D. (1981) in aerospace structures from MIT. From 2003 to 2006 he served as the executive director of the Cambridge–MIT Institute, a joint venture with Cambridge University, funded by the British government and industry, with a mission to understand and generalize how universities act as engines of innovation and economic growth. In this capacity, he worked closely with the British government on issues of science and innovation policy. For the previous seven years, he served as the department head of aeronautics and astronautics at MIT and lead the strategic realignment of the department.

Dr. Crawley's earlier research interests centered on structural dynamics, aeroelasticity, and the development of actively controlled and intelligent structures. He is the author of numerous journal publications in the *American Institute of Aeronautics and Astronautics (AIAA) Journal*, the *American Society of Mechanical Engineers (ASME) Journal*, the *Journal of Composite Materials*, and *Acta Astronautica*. Credited with being one of the early contributors to the field of active structural control, several of these publications have more than 100 citations, and one has more than 700. For his work in the field, Professor Crawley was awarded both the AIAA Structures, Structural Dynamics and Materials Award and the ASME Adaptive Structures Medal. He is co-author of two books in the field.

Acceptance Remarks by Edward F. Crawley



Edward F. Crawley, professor of aeronautics and astronautics, Massachusetts Institute of Technology, and recipient of the Gordon Prize. Photo by Event Digital Photography Inc.

I would like to start on a personal note by thanking my father, who was a high school teacher in Cambridge, Massachusetts. He taught me to always focus on the welfare of the students and on their learning. My thanks and love go to my wife, Karen, who is here tonight, for her support and tolerance. Of course, I also extend my thanks to my colleagues in the Department of Aeronautics and Astronautics at MIT and around the world at the more than 50 CDIO (Conceive-Design-Implement-Operate) collaborator universities without whom this effort could not have been possible.

I also would like to thank **Bernie Gordon** and the academy—not for awarding me this honor, but for *creating it*. For those of you who do not toil in the trenches of educational innovation on a daily basis, it might be hard to understand just how difficult it is to influence the educational system. Universities are, by design, extremely stable organizations.

Would it not, therefore, seem obvious that the primary function of a university is to educate students and that this educational role is the *raison d'etre* of a university? Yet, the way universities are now rated and evaluated clouds this primary historical mission. Education is now considered part of a triple helix of university outcomes along with research and economic development.

Certainly, there are superb researchers at universities, as evidenced by my colleagues who received other awards here this evening, and certainly a university's role in regional and national economic development is important. But it is a maxim of organizations that you get the behavior you incentivize.

We have constructed in America an incentive system that recognizes individual scholars largely for their research output—we count papers published in journals, measure citations to these papers, rank journals by impact, and then evaluate universities by these measures. This self-referential system may be appropriate for some disciplines, but I do not believe it serves engineering well. Engineers need educational outputs that impact their practice, but this system introduces a strong bias in organizational incentives toward research and away from education.

We need to start a national dialogue to regain a balance among the roles played by universities, a partnership to realign missions and incentives. This dialogue should empower university leaders to unambiguously declare that education and well-educated students are the primary outputs of universities. Industry should be engaged in providing meaningful feedback to universities on their performance as educators.

We should also improve how we prepare university faculty as instructors. Does it seem anomalous to anyone else in the room that to teach 12th grade in America, you need a master's in education, but to teach 13th grade, you do not need a single day of education on teaching and learning? Part of the dialogue should be on the development of a national model for preparing instructors to teach on the university level.

There should also be authorization (and appropriations) for the National Science Foundation and mission agencies to provide funding, not only for educational research, but also for the far more organizationally challenging mission of transition and implementation. Research is important, but an enormous amount of what we know about learning is not being applied in today's university classroom.

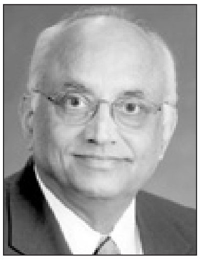
Finally, NAE and professional societies should strengthen their roles in providing recognition for professional development programs, such as NAE's Frontiers of Engineering Education, and recognition for excellent educators.

I am hopeful that such a national dialogue will succeed in America. As I travel to other countries that have CDIO programs, I often have the privilege of meeting with ministers of science, innovation, or higher education or with Chuck Vest's counterparts—presidents of national academies of engineering. Often, they bemoan the state of engineering education in their countries.

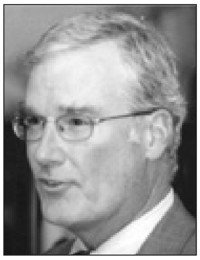
They ask, "Why are students not interested in studying engineering? Why are faculty not as dedicated to education as they might be?" I often ask in return: "Are contributions to engineering education part of the criteria for election to your national academy?" I have found no country, except America, in which they are. I then ask if there is a prestigious national award for excellence and innovation in education? I have found only a few outside America where there is.

This academy can play a leading role in the world by establishing the principle that the education of engineers is an important endeavor of the university. We need to build on this to promote the future of our nation and our national welfare. I believe we can do it. We have a very strong basis, brought about in large part by the moral and financial contribution of Bernie Gordon. I would like to close the evening by thanking him again.

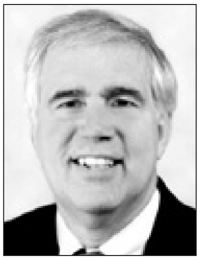
Foreign Secretary and Councillors Elected


Venkatesh Narayanamurti


Alice M. Agogino


Paul R. Gray


Julia M. Phillips


Richard A. Meserve


George Bugliarello


Bradford W. Parkinson

This spring, NAE elected a new foreign secretary, reelected three incumbent councillors, and elected one new councillor. All terms begin July 1, 2011.

Venkatesh (Venky) Narayanamurti, Benjamin Peirce Professor of Technology and Public Policy at the Harvard School of Engineering and Applied Sciences and director of the Science, Technology and Public Policy Program at Harvard Kennedy School, was elected to a four-year term as NAE foreign secretary.

Alice M. Agogino, professor of mechanical engineering at the University of California, Berkeley; **Paul R. Gray**, Executive Vice Chancellor and Provost, Emeritus, and Professor Emeritus in the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley; and **Julia M. Phillips**, director of the Nuclear Weapons Science and Technology Programs at Sandia National Laboratories, were reelected to three-year terms as councillors. **Richard A. Meserve**, president of the Carnegie Institution for Science, was newly elected to a three-year term as councillor.

George Bugliarello, President Emeritus and Institute Professor at Polytechnic Institute of New York University, passed away on February 18, 2011. On June 30, 2011, he would have completed eight consecutive years of service as foreign secretary.

On June 30, 2011, **Bradford W. Parkinson**, Edward C. Wells Professor of Aeronautics and Astronautics Emeritus at Stanford University, completed four continuous years of service as councillor. He was ineligible for a continuing three-year term which would have exceeded the maximum six years of continuous service allowed under the Academy's bylaws.

NAE Regional Meetings

Viterbi School of Engineering and NAE Hold Meeting on Megacities

An NAE regional meeting was held in conjunction with a national meeting hosted by the University of Southern California (USC) Viterbi School of Engineering on February 22, 2011. The presentations and discussions focused on the challenges of planning, building, and managing megacities, and speakers included distinguished academics with expertise in energy, environmental quality, infrastructure, transportation, and natural disasters. The NAE portion of the event included poster presentations on parallel research by USC faculty.

Dean **Yannis C. Yortsos** opened the meeting by framing the challenges posed by megacities as part of the NAE Grand Challenges, which include "restoring the urban infrastructure" and "ensuring access to clean water." "We are thrilled," he said, "to host this NAE regional meeting at USC and welcome back the academy to the heart of Los Angeles—one of the two megacities in the U.S."

In subsequent remarks, NAE President **Charles M. Vest** explained that the regional meeting was part of an outreach effort by NAE. He addressed many of his remarks directly to students of a "magnet" high school who were in the audience, particularly when he described NAE's efforts to engage the public and encourage bright young people to pursue careers in engineering.

The first presentation, by **Thomas O'Rourke**, Thomas R. Briggs Professor of Engineering, Geotechnical Disciplines, Cornell University, included a review of characteristics and directions for future infrastructure, as illustrated in case studies of planning projects in New Orleans, San Francisco, Los Angeles, and New York. He quoted President Dwight D. Eisenhower, commander of Allied Forces in Europe during World War II, who said, "In preparing for battle, I have always found that plans are useless; but planning is indispensable."

Donald L. Paul, William M. Keck Chair of Energy Resources and director, USC Energy Center, gave the next presentation. He provided a comprehensive picture of energy requirements, particularly for transportation in a megacity. He also described a recent project by the Los Angeles Department of Water and Power and the USC Smart Grid. In summarizing the project, he said, "Security—energy security in all forms—physical, national, cyber—are [sic] key issues for society, business, and government." He also stressed that "population growth and the enormous scales" of infrastructure for megacities must be taken into account.

In the next talk, on water usage in megacities, particularly Los Angeles, David Sedlak, professor of civil and environmental engineering, University of California, Berkeley, noted that all current water supplies for Los Angeles are under threat, and the city must find alternative water resources. He suggested that the city might reinvent its urban water systems through a combination of conservation, desalination, reuse, and urban water harvesting.

The presentation by Constantinos Sioutas, Fred Champion Professor in the Astani Department of Civil and Environmental Engineering at Viterbi, was on the effects of airborne nanoparticles emitted by road traffic and other modes of transportation. Nanoparticles in the ambient air have recently been identified as major health risks, and Professor Sioutas argued for light rail, which would reduce nanoparticles in the air, as a viable alternative to automobiles.

The next speaker was Martin Wachs, senior principal researcher and former director of the Transportation, Space and Technology Program, RAND Corporation. He discussed the need to increase (rather than decrease) mobility in megacities, and, he said, this must be done by using alternative means of transportation. He noted the urgency of planning and deploying alternative transport systems in the face of a worldwide trend of constantly increasing numbers of cars, which are replacing public transportation, especially in rapidly developing countries.

The final presentation was by Thomas Jordan, William M. Keck Professor of Earth Sciences, USC, and director of the Southern California Earthquake Center. Dr. Jordan explained the crucial importance of fine-scale simulation in predicting the impact of natural hazards, particularly earthquakes. Capturing the effects of an earthquake, he said, requires high-performance computing and the development of accurate numerical codes. Simulations that can conduct and compare alternative scenarios would greatly improve not only advanced warning of impending natural disasters, but also preparedness for responding to them.

The sessions were moderated by Jean-Pierre Bardet, professor and chair of the Astani Department and director of the USC Center on Megacities, and Roger Ghanem, a professor in the same department. A webcast of the event is available at *http://viterbi.usc.edu/nae2011/*. The complete program and speaker biographies can be found at *http://viterbi.usc.edu/assets/122/73503.pdf*.

Meeting on Engineering the Future of Health Care at the University of Texas, Austin

Providing affordable health care to people in developing nations, using protein drug therapies to treat cancer, and transforming a patient's own cartilage to treat burn injuries were just three of the challenges described during the April 7 National Academy of Engineering (NAE) Regional Meeting, Engineering the Future of Health Care. The meeting was hosted by The University of Texas at Austin at the AT&T Executive Education and Conference Center.

Speakers included engineering experts from across the country, who described recent developments in health care technology that are sure to have a major global impact. The attendees were welcomed by **Charles Vest**, president of NAE, and Dean Gregory Fenves of the Cockrell School of Engineering, The University of Texas at Austin.

The talk by the first speaker, **Rebecca Richards-Kortum**, Stanley C. Professor of Bioengineering, Rice University, and an NAE member, was titled "From Cell Phones to Cell Biology: High Tech, Low Cost Solutions for Global Health." She set the stage for her talk by reminding her listeners that "Ninety percent of the world's children live in impoverished nations and face enormous health challenges." Health care innovation, she said, should be available to all of the world's citizens.

"We need a new generation of leaders who can work across disciplines and cultures on technology and delivery of technology," she said. She believes those leaders can be found among her undergraduate students at Rice University, who are working to solve global health problems and to put their ideas into practice. For example, some students are equipping bare-bones laboratories in Malawi and Congo with portable, low-cost technologies, such as a diagnostic lab powered by a laptop battery that can fit into a backpack.

She described a microscope, also developed by her students, that uses a laptop battery, an LED light, and an iPhone® camera and can provide low-cost imaging capable of detecting changes in cervical cells—all for $3,000. This critical tool will save many lives in nations where cervical cancer is still a leading cause of death among women.

Richards-Kortum's students have also developed devices that help deliver HIV medication to mothers to prevent transmission of the virus to their babies and that help newborns with underdeveloped lungs breathe. "Infant mortality rates are a big indicator of political upheaval," she said. "So this is in our interest, and we have a responsibility as educators to make the whole world visible to our students." She concluded by stating her belief that we cannot have a safe world until we have a more equitable world.

NAE member **George Georgiou**, professor of biomedical and chemical engineering, The University of Texas at Austin, is co-developer of the leading treatment for inhaled anthrax, which is currently being tested. His talk, "Molecular Analysis of Patients' Immune Responses: The Next Revolution in Disease Diagnosis and Therapy," was on using protein therapeutics for treating cancers and other ailments, such as Hepatitis B and pneumococcal infections. He discussed challenges to the development of some very expensive drugs and the need for physicians and engineers to become more involved in drug development. "We need more people who understand

Robert Langer speaking to a rapt audience at the University of Texas, Austin. Photo by Emily C. Kinsolving.

biology . . ." he said. "Engineers have to become more proficient in this."

Georgiou also talked about his work on next-generation DNA sequencing and antibodies that can both kill cancer cells and prime the immune system to fight against tumors. So far, he said, antibodies have been used successfully to treat ovarian cancer, breast cancer, and lymphoma.

Robert Langer, David H. Koch Institute Professor, Massachusetts Institute of Technology, and a member of NAE, Institute of Medicine, and National Academy of the Sciences (NAS), was the third speaker. His presentation, "Engineering and Health Care: From the Discovery of the First Angiogenesis to the Development of Controlled Drug Delivery Systems and the Foundation of Tissue Engineering," focused on using polymer-based treatments for cancer and cardiovascular disease, including using shape-area metals for minimally invasive surgery. Shape-area metals, he explained, are made with polymers, whose behavior can change depending on conditions such as heat or light. Thus a material that acts one way when it is outside the body may behave differently when it is inserted into the body. When these materials are used, patients' recovery time from some major surgeries can be drastically shortened.

The meeting continued with **Mark E. Davis**, Warren and Katharine Schlinger Professor of Chemical Engineering at the California Institute of Technology and an NAE and NAS member. Davis, who is an expert on new materials for drug and nucleic acid delivery spoke on "Engineering Nanoparticle Medicines for the Treatment of Cancer."

The last presentation was by **Joseph C. Salamone**, NAE member and chief scientific officer of Rochal Industries LLP, a privately owned research company that develops polymeric materials for the treatment of wounds and burns. In his talk, "Bioengineering Health Care Advances in Ophthalmology and Wound Care," he described how a patient's cartilage could be transformed to help heal burns. Dr. Salamone holds more than 190 U.S. patents or patent applications in the field of eye care and wound care.

Closing remarks were given by **Nicholas Peppas**, chair of the Department of Biomedical Engineering at The University of Texas at Austin and chair of the organizing committee for the meeting. Other members of the committee were George Georgiou, **Thomas Hughes**, **Tinsley Oden**, **Don Paul**, and **Isaac Sanchez**—all professors in the Cockrell School of Engineering. The approximately 180 participants enjoyed a breakfast and a meeting of the attending NAE members, as well as social events during and after the meeting.

Meeting on Ethics and Genetics in the Digital Age at Harvard University

When five Texas parents found out in 2009 that the Department of State Health Services had saved DNA samples collected through its newborn screening program and was sharing them with researchers (and, as it turns out, federal investigators), they sued the state. This complex case, involving health care policy, consent, medical research, forensics, and civil rights, exemplifies the debate unfolding nationwide over privacy and autonomy in genetics.

The class-action lawsuit, which resulted in the incineration of more than four million blood samples, stirred a range of reactions among experts in medical ethics, law, public policy, research, and entrepreneurship during a symposium on April 14, "Privacy, Autonomy, and Personal Genetic Information in the Digital Age" held April 14.

Organized by **Cherry A. Murray**, dean of the Harvard School of Engineering and Applied Sciences (SEAS), and co-hosted by the American Academy of Arts and Sciences in Cambridge, Massachusetts, the symposium was held in conjunction with regional meetings of the National Academy of Engineering (NAE) and Institute of Medicine (IOM). Opening remarks were given by Murray, Leslie Berlowitz, president of the American Academy of Arts and Sciences, Harvey Fineberg, president of IOM, and **Charles Vest**, president of NAE.

The symposium featured two panel discussions on the "promise and perils" of creating digital repositories of genetic records and the policy implications of an individual's right to access, control, and interpret his or her genetic data.

During the first panel discussion, moderated by Jeffrey S. Flier, IOM member and dean of Harvard Medical School, panelists examined the risks and benefits of "crowdsourcing" genetic data in light of recent technological advances. In the last 10 years, with the advent of high-speed, low-cost genetic sequencing methods, services that provide genome sequencing and analysis directly to the public have proliferated. Through websites such as *23andMe.com*, *deCODEme.com*, and *Navigenics.com*, anyone can provide a sample of saliva or blood and pay to have it screened for certain genetic traits—with varying levels of guidance (or no guidance) from physicians or genetic counselors. Health care providers, too, like those in Texas, are amassing records of genetic information along with family medical histories and epidemiological data.

The results may be shared among participants, creating an online community—described by one panelist as “Facebook for genetics”—or among medical researchers who may benefit by gaining a better understanding of the role of genetics in diseases like diabetes and cancer.

Many experts believe genetic information should have a different level of protection than health care records. Some think it needs more protection because it is inheritable and has great implications for family members; others argue that it needs less protection because it represents only potential outcomes, rather than conditions actually made manifest.

The Food and Drug Administration regulates genetic testing as a diagnostic tool under the Federal Food, Drug, and Cosmetic Act, and individual states can enforce their own health care and privacy laws. New York, for example, requires that genetic tests be ordered by a licensed medical practitioner. In addition, the federal Genetic Information Nondiscrimination Act of 2008 prohibits discrimination in employment and health insurance on the basis of genetic makeup.

Even with these safeguards, genetic analysis and information privacy remain a “wild West” for ethicists, legal experts, and policy makers. For example, genetic altruists, such as those who volunteer to participate in the Personal Genome Project (PGP), headed by George Church, a symposium panelist and professor of genetics at Harvard, do so because the data are essential for research into the causes and treatment of diseases. The question arises, however, if certain risks for these early adopters of the technology are inevitable.

Participants in PGP and other sequencing services are required to sign consent forms (and, for PGP, to pass an entrance exam), but the text of those forms and the degree to which a signature represents *informed* consent vary among companies and health care providers, as well as states.

Professor Flier asked whether subjects can ever be fully informed. A person who signs a form today, he said, might be consenting to applications that “can’t even be imagined during the lifetime of the individual.” Panelist Latanya Sweeney, an expert in digital privacy and Visiting Professor at Harvard and MIT asked, “To what extent can one actually know the consequence of releasing that data? People have a horrible time calculating their risk of harm…. Historically, that’s been the role of privacy policy, because we’re often in that position.”

Church suggested that with time and education, public familiarity with genetics will increase as it has with computers and smart phones. Hank Greely, director of the Center for Law and the Biosciences at Stanford University, agreed that education is essential; he warned against a “mismatch between public understanding and expectations—public knowledge and scientific practice.”

“In research we have a relationship of trust with our participants, and that trust has to be based on a relationship with truth,” said Christine Patch, chair of the British Society of Human Genetics. “I think it’s important that people don’t assume they have more privacy than they have.”

Referring back to the Texas case, Latanya Sweeney added that, in her opinion, “Not to have the individual as a first-hand party to the decision making, allowing them control, is a formula for disaster.”

The second panel discussion, moderated by Jonathan Zittrain, professor, Harvard Law School, Harvard Kennedy School of Government, and SEAS, hinged on the definition of autonomy. Zittrain asked whether an individual should have the right to obtain his or her own genetic information through a site like 23andMe.com without, for example, a prescription.

“I’m all for people being able to do it,” said John Schumann, assistant professor of medicine and faculty associate of the MacLean Center for Medical Ethics at the University of Chicago, who is a practicing physician. To require medical guidance for such a test, he said, is “burdensome and very paternalistic.”

Zittrain, who has been a participant in 23andMe himself, displayed a test result at the front of the room, which showed he had a higher-than-average risk of developing venous thromboembolism. He remarked that, knowing this, he was more likely to get up and stretch his legs during cross-country flights.

Results like that, or simple ones like finding out the sex of an unborn child, may be relatively easy to interpret. “Everybody understands what that means,” said Art Beaudet, IOM member and chair of the Department of Molecular and Human Genetics at Baylor College of Medicine. “But there may be other times when it’s a little more complex. You might be at risk of hemochromatosis. . . . Will you follow up on it, and will you understand it?"

"The idea is not to prevent people from making certain decisions," said Gaia Bernstein, professor of law at Seton Hall University. "The idea is to give them more information so they can make more informed decisions. In my mind, this enhances their autonomy, not reduces it."

As the allotted time ran out and the debate continued, Zittrain tapped the podium and quipped, "It just shows it is appropriate to be in this building [the Academy of Arts and Sciences] right now; this is as much art as science."

Video of the event will be available online at *http://academy.seas.harvard.edu* in the coming weeks. Biographies of all 12 participants are also available.

A Message from NAE Vice President Maxine L. Savitz

Maxine L. Savitz

I am pleased to report that 2010 was a good year for fundraising. Thanks to your generosity, we raised almost $2.5 million in new gifts and pledges for NAE. More than $1.2 million of this was for the NAE Independent Fund, an unrestricted fund that provides strategic flexibility for NAE to take on high priority projects for which funding from traditional government sponsors is not available.

Philanthropic gifts now make up 30 percent of NAE's operating budget. Your support not only helps us fulfill our mission to "promote the technological welfare of the nation," but also ensures our independence and the high quality of our work. While government provides critical funding for projects that address the specific questions they pose, private donations enable us to address long-range challenges that are critical to our nation's future.

I extend my sincere gratitude for some remarkable commitments from our members and friends in 2010:

- **Stephen D. Bechtel, Jr**., whose foundation provided very generous funding for the current study on integrated science, technology, engineering and math (iSTEM) education.
- **John Evans Estate** for a bequest of $890,000 to support improving public understanding of engineering.
- **John and Janet Swanson** for establishing a charitable gift annuity (CGA) that will provide unrestricted support for NAE in the future.
- **Joan and Irwin Jacobs** for providing matching funds for gifts from the Class of 2010 that raised almost $48,000.
- **The DuPont Corporation** for its latest pledge payment for core support of NAE.

Collectively, your contributions have made it possible for us to respond to complex issues that affect our nation's safety, long-term economic strength, and quality of life. Some of these activities are highlighted below:

Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5. In 2010, the Academies published a follow-on report to the landmark 2005 study that resulted in the passage of the America COMPETES Act in 2007. The follow-on study concluded that our country's outlook has actually worsened in the interim and that for the United States to remain competitive in the global marketplace, we must invest in people, research, and innovation as recommended in the original report. We are pleased that the America COMPETES Act was reauthorized by Congress in December 2010.

Public Understanding of Engineering. We all hope our economy will prosper, our populace will be healthy and secure, and that our standard of living in the 21st century will be high. Engineering will be crucial to realizing these hopes. To ensure that we have a vibrant engineering workforce, we must increase the quantity, quality, and diversity of our engineers and change the way people perceive and talk about engineering. NAE continues to work on educating young people and the public about the importance of engineering to our society. The projects described below brought us closer to achieving those goals in 2010:

- **Changing the Conversation (CTC).** The overall goal of this project is to address "the public's (mis)understanding of engineering." Last year, NAE created a website (*engineeringmessages.org*) designed to improve outreach to the public by the engineering community. The site provides both an interactive forum for posting comments, questions, and information and messaging-related tips and resources. Last fall, NAE also held a workshop on engineering messaging during which more than 50 individuals from various segments of the engineering community discussed how organizations have used CTC messages in their outreach activities, explored how messaging can be used to "rebrand" engineering, and considered the pros and cons of large-scale communications campaigns.
- **U.S. Science and Engineering Festival.** A highlight of the October 2010 inaugural USA Science & Engineering Festival was a collaborative exhibit by NAE and Walt Disney Studios that blended themes from the recent motion picture "TRON: Legacy" and the NAE Grand Challenges for Engineering. Interactive activities included performing brain surgery on a computer-generated replica of a real brain; using 3-D scanning to understand how this technology brings together the real and virtual worlds; and experiencing a trip into the "TRON: Legacy" digital grid through 3-D light painting, an activity created by Disney especially for the festival. The exhibit, which was supported by a generous gift from the S.D. Bechtel, Jr., Foundation, attracted thousands of visitors and helped educate kids of all ages about the importance of engineering.
- **NAE Grand Challenges for Engineering** have taken on a life of their own, and we hope they will inspire the next generation of engineers. Grand Challenges Summits in Raleigh, Phoenix, Chicago, Boston, Seattle, Durham, and Los Angeles attracted leaders in business, government, and academia, and many of the best U.S. universities and engineering schools are joining this grassroots effort.

As we approach NAE's 50th anniversary in 2014, we will continue to focus on building our endowment to ensure our long-term financial strength. In addition to our traditional estate planning brunch at the NAE Annual Meeting, we plan to host estate planning seminars in conjunction with selected NAE regional meetings. These events will provide valuable information about deferred giving and estate planning

On behalf of the NAE Council, I thank all of the members, friends, partner corporations, foundations, government sponsors, and organizations that supported NAE in 2010. We are grateful for your continued involvement and generosity, and we look forward to working together to address the engineering challenges that lie ahead.

Maxine

Maxine L. Savitz
NAE Vice President

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The National Academy of Engineering gratefully acknowledges the following members and friends who made charitable contributions during 2010. Their collective, private philanthropy helps to enhance the impact of NAE as advisor to the nation.

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Calendar of Events

June 27–30	International Council of Academies of Engineering and Technological Sciences (CAETS) Mexico City, Mexico
July 20–21	Grand Challenge Scholars Program Workshop Austin, Texas
August 2–4	NAE Council Meeting Woods Hole, Massachusetts
August 5–6	NRC Governing Board Meeting Woods Hole, Massachusetts
September 12	Workshop on Energy Ethics in Science and Engineering Education

All meetings are held in Washington, D.C., unless otherwise noted.

In Memoriam

NEAL R. AMUNDSON, 95, retired professor, University of Houston, died on February 16, 2011. Dr. Amundson was elected to NAE in 1970 "for pioneering contributions to the fundamental analysis of chemical processes and leadership in chemical engineering education."

PAUL M. ANDERSON, 86, president, Power Math Associates, died on April 26, 2011. Dr. Anderson was elected to NAE in 2009 "for contributions that have advanced the analysis and control of electric power systems worldwide."

PAUL BARAN, 84, chairman, NovoVentures Inc., died on March 26, 2011. Mr. Baran was elected to NAE in 1996 "for the concept of packet-switching and for its technical development and utilization."

THOMAS D. BARROW, 86, Thomson-Barrow Corporation, died on January 27, 2011. Dr. Barrow was elected to NAE in 1974 "for leadership in the development of geologic analysis and methods contributing to worldwide petroleum resource discoveries."

GEORGE BUGLIARELLO, 83, president emeritus and university professor, Polytechnic Institute of NYU, died on February 18, 2011. Dr. Bugliarello was elected to NAE in 1987 "for outstanding contributions in biomedical engineering, fluid mechanics, and sociotechnology, and for leadership in technological education."

EDWARD J. CAMPBELL, 82, retired president, J.I. Case Company and Newport News Shipbuilding, died on October 8, 2010. Mr. Campbell was elected to NAE in 1991 "for outstanding leadership in advancing maritime design and manufacturing techniques."

MOUSTAFA T. CHAHINE, 76, senior research scientist, Jet Propulsion Laboratory, died on March 23, 2011. Dr. Chahine was elected to NAE in 2009 "for leadership in determining the structure and composition of the Earth's atmosphere from space observations."

HARRY W. COOVER, 94, retired vice president, Eastman Kodak Company, and consultant, died on March 26, 2011. Dr. Coover was elected to NAE in 1983 "for significant contributions in widely diverse fields of applied chemistry, management of industrial research, engineering and development, and national research activities."

ROBERT L. FLEISCHER, 80, research professor of geology, Department of Geology, Union College, died on March 3, 2011. Dr. Fleischer was elected to NAE in 1993 "for contributions to the development and diverse applications of high-temperature materials, solid solution hardening, and etched particle track detectors."

WILLIAM A. GROSS, 86, professor and dean, emeritus, The University of New Mexico, and consultant, died on February 20, 2011. Dr. Gross was elected to NAE in 1996 "for air bearings research leading to magnetic disk memories and low-cost video recording and for industrial and academic leadership."

W. JACK HOWARD, 88, retired executive vice president, Sandia National Laboratories, died on September 13, 2010. Mr. Howard was elected to NAE in 1979 "for contributions to nuclear ordnance engineering, particularly in systems concepts, command, control, intelligence, and safety."

RIK HUISKES, 66, professor of biomedical engineering, Department of Biomedical Engineering, Eindhoven University of Technology, Netherlands, died on December 24, 2010. Dr. Huiskes was elected a foreign associate of NAE in 2005 "for advancing the understanding of how bone prostheses affect the functioning of the living human skeleton."

CHARLES H. KAMAN, 91, chairman emeritus, Board of Directors, Kaman Corporation, died on January 31, 2011. Mr. Kaman was elected to NAE in 1967 "for aeronautical research and development."

CHRISTIAN J. LAMBERTSEN, 93, Emeritus Distinguished Professor of Environmental Medicine, University of Pennsylvania, died on February 11, 2011. Dr. Lambertsen was elected to NAE in 1977 "for contributions to environmental science and to diving physiology and technology."

JOHN G. LINVILL, 91, Canon U.S.A. Professor of Engineering, Emeritus, Stanford University, died February 19, 2011. Dr. Linvill was elected to NAE in 1971 "for leadership in education as a teacher and writer and, as an administrator, in the development of a reader for the blind based on modern electronics technology."

FRANK A. MCCLINTOCK, 90, Professor Emeritus of Mechanical Engineering, Massachusetts Institute of Technology, died on February 20, 2011. Dr. McClintock was elected to NAE in 1991 "for pioneering and sustained contributions to the understanding of the process of ductile fracture of engineering materials."

KENNETH H. OLSEN, 84, retired chairman, Modular Services, LLC, died on Feburary 6, 2011. Mr. Olsen was elected to NAE in 1977 "for leadership in the design and manufacturing of computers."

OWEN M. PHILLIPS, 79, Decker Professor in Science and Engineering, Emeritus, and principal research scientist, The Johns Hopkins University, died on October 13, 2010. Dr. Phillips was elected to NAE in 1996 "for analyses of multivaried ocean, atmospheric, and geological flow processes of importance in ocean and environmental engineering."

GLENN A. SCHURMAN, 88, retired vice president, production, Chevron Corporation, died on December 30, 2010. Dr. Schurman was elected to NAE in 1980 "for leadership in a major offshore engineering achievement which has advanced deepwater oil production technology."

LEO J. THOMAS, 74, retired executive vice president, Eastman Kodak Company, died on April 11, 2011. Dr. Thomas was elected to NAE in 1984 "for imaginative and productive leadership in the management of science and engineering leading to the development of innovative products for the consumer and commercial-industrial marketplaces."

R. BRUCE THOMPSON, 69, director, Center for Non-destructive Evaluation, Institute for Physical Research and Technology, Distinguished Professor, Materials Science, and Aerospace Engineering, Iowa State University, died on March 7, 2011. Dr. Thompson was elected to NAE in 2003 "for outstanding contributions to nondestructive evaluation, materials processing, and life-cycle management, and for the development of novel ultrasonic technology."

KLAUS D. TIMMERHAUS, 86, professor and President's Teaching Scholar, Department of Chemical and Biochemical Engineering, University of Colorado, died on February 11, 2011. Dr. Timmerhaus was elected to NAE in 1975 "for contributions in research in cryogenic engineering and national leadership in support and development of chemistry and energetics research."

EDWARD WOLL, 96, retired vice president, GE Aircraft Engines, died on December 17, 2010. Mr. Woll was elected to NAE in 1977 "for contributions to the pioneering development and evolution of aircraft gas turbines."

EDWIN L. ZEBROSKI, 89, independent consultant, died on October 19, 2010. Dr. Zebroski was elected in 1981 "for outstanding contributions in fuel performance, reprocessing, advanced reactor designs and safety analyses leading to commercial utilization of nuclear energy."

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at *http://www.nap.edu* or by phone at (888) 624-8373. *(Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2010 Symposium. The extended summaries collected in this volume were the basis for presentations at the National Academy of Engineering 2010 U.S. Frontiers of Engineering (FOE) Symposium. Every year, FOE brings together 100 outstanding young leaders in engineering to exchange information on cutting-edge research and technical work. The 2010 symposium, on September 23–25, was hosted by IBM and held at the IBM Learning Center in Armonk, New York. The topics for the symposium were: cloud computing; engineering and music; autonomous aerospace systems; and engineering inspired by biology. The papers in this volume convey the excitement of this unique symposium series.

NAE member **Andrew M. Weiner**, Scifres Distinguished Professor, School of Electrical and Computer Engineering, Purdue University, chaired the symposium organizing committee. Paper, $40.00.

BioWatch and Public Health Surveillance: Evaluating Systems for the Early Detection of Biological Threats: Abbreviated Version. In the aftermath of September 11 and the anthrax letters, the U.S. Department of Homeland Security (DHS) introduced BioWatch, a federal monitoring system to detect specific biological agents that might be released in aerosolized form. In 2008, at the direction of Congress, DHS asked the Institute of Medicine and National Research Council to convene a committee to (1) evaluate the costs and merits of the current BioWatch program and plans for a new generation of BioWatch devices, (2) review the surveillance of infectious diseases by hospitals and public health agencies in the United States, and (3) determine if BioWatch and traditional surveillance measures are redundant or complementary. The study committee concluded that testing of the current BioWatch program must be conducted to demonstrate its effectiveness and that the program would be more useful if there was more collaboration with public health systems. The committee also recommended that infectious disease surveillance and disease detection resources in both public and private health care systems be re-evaluated and improved, as necessary. This volume provides an abbreviated summary of the full report.

NAE members on the study committee were **Joseph M. DeSimone**, W.R. Kenan Jr. Distinguished Professor of Chemistry and Chemical Engineering, University of North Carolina at Chapel Hill; **Stephen M. Pollock**, Herrick Emeritus Professor of Manufacturing, University of Michigan; and **Jerome S. Schultz**, Distinguished Professor and chair, Department of Bioengineering, University of California, Riverside. Paper, $50.50.

Evaluating Testing, Costs, and Benefits of Advanced Spectroscopic Portals for Screening Cargo at Ports of Entry: Final Report (Abbreviated Version). This letter report is an abbreviated version of an interim report on testing, evaluation, costs, and benefits of advanced spectroscopic portals (ASPs) (issued in June 2009 and updated in October 2009). The letter incorporates findings by the committee since the update was published and clarifies the messages in the interim report based on recent work by the Domestic Nuclear Detection Office. The committee also provides suggestions for improving testing and evaluation, assessing costs and benefits, and deploying ASPs. The letter closes with a reiteration of key points and the committee's findings and recommendations.

NAE member **Richard E. Blahut**, Henry Magnuski Professor, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, was a member of the study committee. Paper, $15.00.

Evaluation of U.S. Air Force Preacquisition Technology Development. Many delays and cost overruns in U.S. Air Force (USAF) programs can be attributed to the incorporation of advanced technologies into major systems. The Air Force is trying to determine the best way of using existing policies, processes, and resources to document and execute technology development, including ways to facilitate the rapid acquisition of revolutionary capabilities and the more deliberate acquisition of evolutionary capabilities. This report provides a review of the current state of USAF technology development and the environment in which new technology is acquired. The committee's recommendations are based on best practices in government and industry acquisition.

NAE member **Donald C. Fraser**, Draper Laboratory (retired), was vice chair of the study committee. Paper, $33.75.

Intelligence Analysis for Tomorrow: Behavioral and Social Scientific Foundations. The U.S. intelligence community is a complex enterprise that depends on how well its people perform. Although they use sophisticated technologies, people ultimately must rely on their own abilities to identify, synthesize, and communicate information on which the nation's security depends. Therefore, intelligence operatives must be well trained, highly motivated, thoughtful individuals, and intelligence organizations must be able to value and coordinate their capabilities. The papers in this volume provide up-to-date scientific guidance for improving individual and group judgments and communication among analysts. The opening chapter focuses on the structure, missions, operations, and characteristics of the intelligence community. The following 12 papers provide in-depth reviews of key topics related to analytic methods, analysts, and organizations. Each paper documents the latest advances in relevant science and can be used as a stand-alone resource. As a collection, this volume provides a broad perspective on issues involved in making difficult decisions and analytic processes and an evidentiary base for the National Research Council report, *Intelligence Analysis for Tomorrow: Advances from the Behavioral and Social Sciences* (see below).

NAE member **Edward H. Kaplan**, William N. and Marie A. Beach Professor of Management Sciences, School of Management; professor of public health, School of Public Health; and professor of engineering, School of Engineering and Applied Science, Yale University, was a member of the study committee. Paper, $70.00.

Intelligence Analysis for Tomorrow: Advances from the Behavioral and Social Sciences. The intelligence community has been seeking ways to improve its performance and expand its capabilities. In 2008, the Office of the Director of National Intelligence asked the National Research Council to establish a committee to synthesize and assess evidence from the behavioral and social sciences relevant to analytic methods and their potential applications for the U.S. intelligence community. In this report, the committee offers recommendations for how knowledge based on behavioral and social sciences can be used to improve how the intelligence community characterizes and evaluates analytic assumptions, methods, technologies, and management practices. Behavioral and social scientific knowledge can also help improve all phases of the analytic cycle, including the recruitment, selection, training, and motivation of analysts; the mastery and deployment of analytic methods; the organization of day-to-day work by analysts, as individuals and teams; and communication with customers. The committee offers five general recommendations for practical ways to apply the behavioral and social sciences to achieve both immediate and long-term benefits at modest cost and with minimal disruption.

NAE member **Edward H. Kaplan**, William N. and Marie A. Beach Professor of Management Sciences, School of Management; professor of public health, School of Public Health; and professor of engineering, School of Engineering and Applied Science, Yale University, was a member of the study committee. Paper, $30.25.

Engineering Aviation Security Environments—False Alarm Reduction: Interim Report (Letter Report). The Transportation Security Administration (TSA) was created as a separate entity under the U.S. Department of Transportation as part of the Air Transportation Security Act in 2001. As of December 31, 2002, all checked baggage on U.S. flights had to be scanned by explosive detection systems (EDSs). Because EDS equipment had to be procured and installed quickly and universally, attention was focused on already certified systems (mostly computed tomography scanners) and procedures for screening where certified equipment was not yet available. The U.S. Department of Homeland Security asked the National Research

Council to conduct a study on EDSs currently used in airports and the problem of false positives. The committee assesses the impact of false positives on personnel and resource allocations and recommends (1) ways to mitigate false positives without increasing false negatives and (2) related short- and long-term research. The recommendations in this letter report will be included in the final report.

NAE members on the study committee were **B. John Garrick**, independent consultant, Laguna Beach, California, and **Gary H. Glover**, professor of radiology, Lucas Imaging Center, Stanford University. Free PDF.

Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. Decisions made today to reduce emissions of carbon dioxide and other greenhouse gases from the burning of fossil fuels will affect climate change not just for the next few decades, but for centuries, perhaps millennia, to come. According to this new report, climate science can now quantify relationships between increases in atmospheric carbon dioxide, global warming, and changes in climate (e.g., changes in stream flow, wildfires, agricultural productivity, extreme heat waves, and sea level rise). Based on analyses and information in the scientific literature, the study committee quantifies outcomes for different stabilization targets (i.e., concentrations of greenhouse gases). Although no specific targets are recommended, these estimates shed light on relationships among emissions, greenhouse gas concentrations, temperatures, and impacts. The committee's science-based arguments make a strong case for the importance of 21st century choices to achieve long-term climate stabilization.

NAE member **Dennis P. Lettenmaier**, Robert and Irene Sylvester Professor of Civil and Environmental Engineering, University of Washington, was a member of the study committee. Paper, $47.00.

Managing University Intellectual Property in the Public Interest. The Bayh-Dole Act of 1980 changed federal policy to require more uniformity in how research agencies treat inventions based on work they sponsor. Up to then, if a government agency funded university research, the agency retained ownership of the knowledge and technologies that resulted, but very little was commercialized. As a result of the Bayh-Dole Act, the number of patents and licenses increased, raising question about whether this would inhibit other kinds of knowledge transfer. Concerns have also arisen that universities might be tempted to steer researchers away from curiosity-driven topics and toward applied research that could yield financial returns. To address these concerns, the National Research Council convened a committee of experts from universities, industry, foundations, and other organizations, as well as scholars of the subject, to review the effects of the current system on technology transfer and to recommend improvements. This volume provides summaries of the committee's principal findings and recommendations.

NAE member **Edward D. Lazowska**, Bill & Melinda Gates Chair in Computer Science and Engineering, University of Washington, was a member of the study committee. Paper, $31.75.

Research Opportunities in Corrosion Science and Engineering. The field of corrosion science and engineering is on the threshold of important advances in lifetime prediction and technological solutions, enabled by the convergence of experimental and computational length and timescales and new modeling techniques. Nevertheless, corrosion is rarely considered a factor in product designs. Even in condition monitoring and predictions of remaining product life (prognosis), corrosion factors are not usually considered. Thus, opportunities are being lost for using materials design and engineering tools to stimulate research on corrosion for quantitative life predictions, the incorporation of state-of-the-art sensors into experimental and materials architectures, and the introduction of measures of environmental degradation. In this report, the major challenges facing the corrosion research community are identified, research opportunities in corrosion science and engineering are highlighted, and a national strategy for corrosion research is developed. The present report is a logical complement to the recently published *Assessment of Corrosion Education*, which argued for academic, industry, and government support for technical education and research.

NAE member **Lyle H. Schwartz**. retired director, Air Force Office of Scientific Research, was a member of the study committee. Paper, $40.25.

2009-2010 Assessment of the Army Research Laboratory. Since 1996, the National Research Council (NRC) Army Research Laboratory Technical Assessment Board (ARLTAB) has provided biannual assessments of the scientific and technical quality of research, development, and analysis programs at the Army Research Laboratory (ARL). ARLTAB is assisted by six NRC panels, each of which focuses on programs in one ARL directorate. When requested, ARLTAB also examines inter-directorate work. The current report is a summary of findings for 2009–2010. During that time, 96 volunteer experts in relevant fields of science and engineering participated in annual visits to ARL to attend formal presentations of technical work, examine facilities, engage in technical discussions with ARL staff, and review ARL technical materials. Based on this information, the review board concluded that the overall quality of ARL's technical staff and work continues to be impressive and applauded ARL for its passionate concern for the end users of its technologies—soldiers in the field—and for its focus on the importance of transitioning technology to support immediate and long-term Army needs. The reviewers also noted that ARL staff continue to expand their engagement with the larger scientific and engineering community. In general, the reviewers concluded that ARL has made significant advances in research and development to achieve its mission requirements.

NAE members of the assessment board are **Lyle H. Schwartz** (chair), senior research associate, Department of Materials Science and Engineering, University of Maryland, and retired director, Air Force Office of Scientific Research; **David E. Crow**. professor of mechanical engineering, University of Connecticut, and senior vice president of engineering, retired, Pratt and Whitney; and **Debasis Mitra**, vice president, Chief Scientist's Office, Bell Labs, Alcatel-Lucent. Paper, $33.50.

Understanding and Managing Risk in Security Systems for the DOE Nuclear Weapons Complex. The United States devotes considerable resources to maintaining security at facilities that house nuclear weapons and significant quantities of special nuclear materials (SNM). In today's budget-constrained environment, these security measures must be not only effective, but also as efficient as possible. Thus, they must incur reasonable costs and impose minimal burdens on the primary missions of organizations that operate U.S. nuclear facilities. To address these issues, Congress directed the National Nuclear Security Administration (NNSA)—a semi-autonomous agency in the U.S. Department of Energy—to ask the National Academies for advice on augmenting security, with a focus on the applicability of quantitative and other risk-based approaches for securing facilities. The study committee concluded that, because there is no comprehensive analytical basis for defining attack strategies that might be used by an adversary or the probabilities associated with them, assessing security risks more quantitatively or precisely would not be the best approach to balancing cost, security, and operations. However, the committee also concluded that using structured thinking processes and techniques to characterize security risk could improve NNSA's understanding of its vulnerabilities, which could lead to more effective resource allocation.

NAE members on the study committee were **Chris G. Whipple** (chair), principal, ENVIRON, and **George E. Apostolakis**, Nuclear Regulatory Commission. Paper, $15.00.

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