Summer 2013

UNDERGRADUATE ENGINEERING EDUCATION

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

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The
BRIDGE

NATIONAL ACADEMY OF ENGINEERING

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NAE News and Notes

Editor's Note

Ronald M. Latanisión

Note from *Bridge* Editor in Chief Ronald M. Latanision

With this issue of the *Bridge,* the NAE will be in the midst of a leadership transition as **Dan Mote** succeeds **Chuck Vest** as president. I have had the opportunity to work a bit with Dan in the context of an Association of American Universities (AAU) initiative on precollege education that I chaired on behalf of the AAU presidents. I look forward to working with him once again. Chuck was president of MIT during my time as a member of the faculty and while it is tempting to mention Chuck's reference to me as MIT's "education czar," I will resist. Instead, I might just mention with fondness the bets that, as alums, we placed on the Michigan–Ohio State football games: the bet included the provision that the winner choose an artifact of the winning school that the loser had to publicly display on the MIT campus for some suitable period of time. Unfortunately for me, he won most of those bets! I had to carry a maize and blue umbrella around campus—rain or shine. But on the one occasion when OSU did win, he wore a Buckeye tie to a faculty meeting! These were short interludes in Chuck's characteristically full agenda.

I also want to thank Guest Editor **Diran Apelian** for his masterful work in assembling this issue of *The Bridge* on the subject of undergraduate engineering education. Education at every level has been important to me, personally and professionally, for a very long time. My roots are in the coal mines of northeast Pennsylvania and the educational system in this country has been at the core of my life. I am concerned now that the intellectual infrastructure in the United States is declining in many of the engineering disciplines that are important to this nation's future. For example, metallurgists, ceramic engineers, welding engineers, corrosion engineers, power systems engineers, high-temperature oxidation experts, cement chemists, and others are very difficult to find among undergraduate and graduate students. We continue to build engineering systems that depend on these disciplines, but the population of students and graduates in such areas is declining. Part of the decline may in my judgment be attributed to the declining research support from agencies that typically fund university research in the United States.

My years of university teaching and research convince me, in a reductionist sense, that most university departments are subject to the following sequence: (1) funding sources drive research, (2) research drives the educational program at both the graduate and undergraduate level, and (3) prospective students look at the education (curriculum) that is offered and vote with their feet in terms of their choice of major. This is in itself not a startling observation. But I suspect that engineering has taken a disproportionate hit in terms of both research funding and student interest for some time. This seems to be true in many engineering disciplines. What concerns me is that the nation's university research enterprise is out of balance in terms of both funding distribution and direction.

Many would argue that the above engineering disciplines are mature and that there are higher priorities for research support. It's true that quite a lot is known about the fundamentals in those disciplines, but without resources for research in a given area, why would a department hire faculty with such interest? And without faculty, there are no students to follow that path of research, and so the intellectual infrastructure that took decades to develop begins to erode. This is the phenomenon at work at this point in my view.

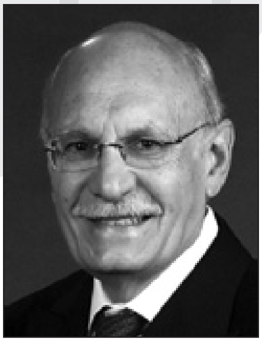
I do understand the need to establish priorities and I do agree that universities should be at the leading edge in terms of their research agenda, but I do not think the national interest is served when the priorities and research agenda are at the expense of disciplines that meet the demand for a workforce that can design, manufacture, inspect, and maintain engineering systems that literally support our daily lives. Power stations, bridges, pipelines, buildings, airframes, and gas turbines are still integral to the American standard of living and commercial enterprise. But US bridges and water works are aging and need attention. Airframes and power plants are being asked to perform beyond their original design life. The country needs not only the skills that address such contemporary engineering systems but also those that are likely to evolve over the decades ahead.

While the above litany represents a problem in my view in terms of engineering education, it represents a challenge and opportunity for the engineering practice. My concern is that with faculty and industrial practitioner retirements, and without the means to replenish these skills, the United States will have a serious engineering dilemma on its hands. Engineering education and research are substantially driven by external funding forces that are seemingly unbalanced.

NAE members, as the leaders of the engineering enterprise, should exercise their sense of technological statesmanship and take a long, hard look at the above issues. This would require, I believe, conversations among university executives, federal agency leadership, and science and technology policymakers that focus not just on ensuring that US research universities have sustained research support but that these funds are distributed in keeping with the national interest in the broadest sense.

I welcome your comments.

Editor's Note



Diran Apelian is Alcoa-Howmet Professor of Mechanical Engineering and director of the Metal Processing Institute at Worcester Polytechnic Institute.

Innovations and Opportunities in Engineering Education

The societal challenges of the 21st century are profound and wide-ranging. Basic needs such as energy, food and water, housing, mobility, and health will become even more acute as the world population exceeds 9 billion. The demands for sustainable development will require redefined and innovative engineering talent and leadership.

In parallel with these changes and challenges, engineering education is embarking on a transformation as significant as the birth of engineering as a profession in the 19th century and the establishment of scientific knowledge as the foundation of engineering in the mid-20th century. These changes are driven by the emergence of a connected, competitive, and entrepreneurial global economy, in which successful engineers increasingly need technical competency and professional skills that differ from what worked in the past. The stage is set for a Renaissance period for engineering education.

But at a time when more engineering talent is needed to address the world's challenges, the number of students who are interested in science, technology, engineering, and mathematics (STEM) is decreasing. This trend is observed in North America and Europe, the exception being the Asian countries, especially China and Korea.

Recent initiatives aim to reverse this trend by attracting the best and the brightest to engineering. As discussed by the authors in this issue, these initiatives teach and nurture the "soft" (people) skills, ensure that the first year of undergraduate study is an engaging one rather than a "turn-off," integrate and offer a holistic approach to engineering education, introduce entrepreneurship and the skills that support it, create pathways to attract talent to STEM-oriented careers, and adapt the curriculum to ensure inclusive learning modalities.

The curriculum of engineering schools is also beginning to change to highlight the creative nature of engineering. The schematic shown in Figure 1 is one that my colleague Grétar Tryggvason and I have used to illustrate the creative function of engineering. It shows dimensions of four broad areas: the humanities, arts, science, and engineering. The humanities are characterized by the study of culture (e.g., literature, art, history), practitioners of the arts create culture, science entails study of the physical world, and engineering involves creation in the physical world.

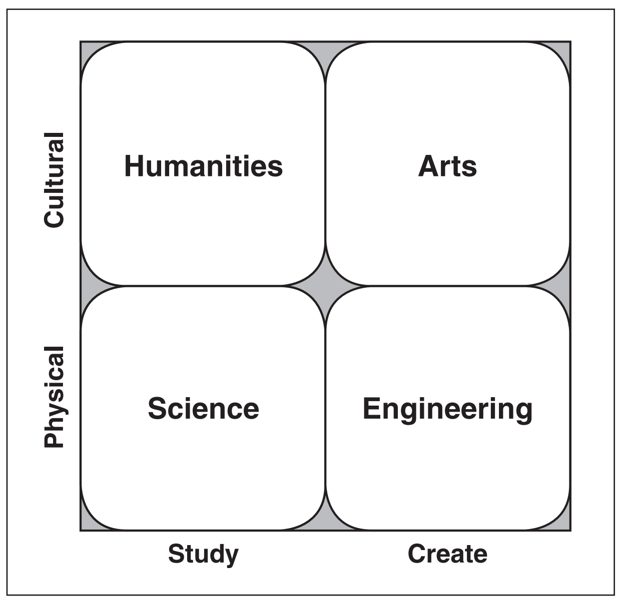


FIGURE 1 Schematic showing dimensions of the humanities, arts, science, and engineering. Reproduced with the permission of John Wiley & Sons, Inc. from Tryggvason G, Apelian D. 2012. *Shaping Our World: Engineering Education for the 21st Century*.

This issue of the *Bridge* focuses on engineering education and how it must evolve to prepare engineers to exercise creativity in developing approaches to the world's challenges. The authors take a critical look at both the design and specific components—both existing and proposed—of the engineering curriculum. They also think broadly about the means of delivery of engineering education, taking advantage of new technological capacities. Moving to the larger picture, they consider the roles of the state and of industry.

First, to prepare students for college study of engineering, Enrique Lavernia and Jean VanderGheynst take up "the algebra challenge," which too often deters students from further study in related subjects. They explain why algebra is particularly difficult for students, and why mastery of it is crucial to STEM education and even high school and college graduation. The authors describe a number of innovative approaches to this subject that can enhance the success of both students and teachers.

Susan Ambrose, coauthor of *How Learning Works: Seven Research-Based Principles for Smart Teaching* (Jossey-Bass, 2010), then assesses undergraduate engineering curriculum as the "Ultimate Design Challenge," describing concepts that have been tested and validated. Importantly, she makes the point that it is time to stop tweaking curricula and instead be audacious and embrace and implement what works. The article is well documented and contains a wealth of references.

Rick Stephens calls for a holistic approach in engineering education, making the point that technical skills alone are not enough. Engineering education must also nurture the "soft" skills that are critical to a successful and satisfying career. He presents four measures to help students learn to work well in teams, communicate effectively, and create useful products.

David Spencer and George Mehler review educational approaches to better prepare engineering students for the changing engineering workforce. They describe opportunities in student-centered education and, interestingly, highlight the importance of—and the feasibility of teaching—character and intuition as well as the freedom to fail.

Tom Byers, Tina Seelig,[1] Sheri Sheppard, and Phil Weilerstein discuss growing interest in entrepreneurship education to prepare students for the innovation economy. In 2011, the National Science Foundation (NSF) awarded a $10 million grant over five years to launch a national STEM Talent Expansion Program (STEP) Center at Stanford University for teaching innovation and entrepreneurship in engineering. The authors review initiatives to teach entrepreneurship throughout the curriculum, and share examples and success stories.

In addition to the content of engineering education, the means of delivery is evolving with the development of new technological capacities. Richard Baraniuk addresses open education and considers the needs and opportunities for changes in methods of delivering instruction. He is a leader of the open education movement, which aims to share knowledge and teaching materials freely over the Internet. He launched Connexions, one of the first initiatives to offer free, open source textbooks via the Web. His comments reaffirm that the world has greatly changed in the past few decades, and those who do not adapt to new paradigms of instructional delivery will be left behind.

Curricular content and delivery are not the whole of engineering education. Engineers must integrate and practice their skills in the real world. To that end, educational collaboration beyond the classroom is essential.

Dennis Berkey and Joanne Goldstein illustrate the role of state government and private enterprises to close the STEM skills gap. Partnerships between institutions of higher education and the state government can address local issues that affect competitiveness and economic well-being. They describe state-sponsored initiatives in Massachusetts, such as community college internships, outreach to parents and students, and workforce training and development to support both career readiness and industry needs.

The final article is by three leaders in engineering education: Tom Katsouleas, **Richard Miller**, and **Yannis Yortsos**. Their focus is the NAE Grand Challenge Scholars Program and how it is attracting young men and women who want to contribute and want to make a difference. What better way to do so than through engineering?

Taken together, these articles clearly show that engineering education as it has been practiced for the last five decades is changing—and must—to adapt to the new realities of the world. And it is about time.

Acknowledgments

My involvement as editor of this issue got started over a lunch of a dozen oysters and a glass of Chablis with *Bridge* Editor in Chief Ron Latanision. I appreciate his invitation and hope I have done justice to the topic. I am especially indebted to Cameron Fletcher, without whom this project would never have come to fruition. She's the best editor I've worked with and helped immeasurably in the writing of this introduction and the organization of the issue.

[1] Byers and Seelig won the NAE Bernard M. Gordon Prize in 2009 for "developing and disseminating technology entrepreneurship educational resources for engineering students and educators around the world."

A fresh approach is critical for teaching algebra, which is the make-or-break moment in K–12 education that prevents countless students from pursuing STEM study or careers.

The Algebra Challenge

Enrique J. Lavernia

Jean S. VanderGheynst

Enrique J. Lavernia and Jean S. VanderGheynst

On January 30, 2013, PBS's *NewsHour* devoted a segment to American schools that have introduced real-world applications to science, technology, engineering, and mathematics (STEM) education while at the same time promoting students' ability to "get the concepts" over the supposed "intelligence" demonstrated by raw scores on tests. The program featured 8th grade students at King Middle School in Portland, Maine, who are designing robots to gather "resources" (in this case, ping pong balls). It also showed students in a statistics class at New York City's High School of Telecommunications Arts and Technology discussing datasets, debating the pros and cons of various polling techniques, and creating their own exit polls—their teacher intends her pupils to become producers of information, not just consumers.[1]

While we're delighted by the mainstream media exposure granted to these pilot programs, we're simultaneously dismayed by the editorial slant that,

Enrique J. Lavernia is dean and Distinguished Professor in the Department of Chemical Engineering and Materials Science and Jean S. VanderGheynst is associate dean and professor in the Department of Biological and Agricultural Engineering, both at the University of California–Davis College of Engineering.

[1] PBS *NewsHour*. Teachers Embrace "Deep Learning," Translating Lessons into Practical Skills (January 30, 2013). Available online at www.pbs.org/newshour/bb/education/jan-june13/charter_01-30.html.

in the 21st century, still regards such efforts as unusual examples of progressive teaching. In this article we focus on the specific need for innovation in the teaching of algebra, which for many students is a "wall" too difficult to scale and stifles their interest in even thinking about further study in mathematics or other STEM areas.

The Need to Transform STEM Education

Many courses suffer from overly structured styles of instruction that have been the norm for half a century: styles that haven't changed despite great technological advances that could—*should*—have prompted exciting new approaches to teaching. The need to transform traditional approaches to teaching STEM is well established, as is the awareness that such approaches, particularly in a "gatekeeper" course such as algebra, are failing miserably.

Traditional instruction methods in algebra are failing miserably.

Anecdotal evidence abounds in middle schools from California to Maine, all of it supported by research and statistical documentation going back at least three decades (Tuma and Reif 1980). More recently, a 2000 study demonstrated that women and underrepresented minority students are particularly ill served by traditional teaching methods (Rech and Harrington 2000), and a 2008 study revealed that the pass rate for Algebra I students was a shockingly low 39 percent nationwide (Gates 2008). A fresh approach is especially critical for the teaching of algebra, which has been recognized as the make-or-break moment in students' K–12 education (Gates 2008; Rech and Harrington 2000). American middle schools, in particular, require innovations that bridge classroom mathematics instruction with other STEM tools and activities, particularly computing (Collins and Halverson 2009; NSF 2008).

Our point: This is not fresh information, and yet *nothing* has been done at a national level. Politicians, school boards, and teachers' unions remain committed to testing requirements, ignoring the increasingly obvious fact that a top-down realignment of STEM education—starting at the university level and working down to kindergarten—may be one of the country's most crucial challenges.

The US Bureau of Labor Statistics reported that more than 800,000 professional information technology jobs would be added during the decade ending in 2016, an increase of about 24 percent (Wright 2009). Although many of these jobs will not require a four-year college degree, all will demand a solid background in computer science (Wright 2009). And in California a study by the Public Policy Institute indicates that by 2025 the state could face a shortage of up to a million college graduates to meet its skilled workforce demands (Johnson and Sengupta 2009).

Despite all of this compelling evidence, US education is actually trending in the wrong direction. Classes in computer science and computer programming—a powerful means to help solve the "algebra crisis"—either remain largely absent from many secondary schools or are declining. The portion of schools offering an introductory programming course dropped from 78 percent in 2005 to 65 percent in 2012, with a corresponding drop from 40 to 27 percent in Advanced Placement classes (Nagel 2009).

People aren't listening. Or, to be more precise, the *right* people aren't listening.

Trends in US STEM Performance and Ranking

The 2011 California STEM Summit, which took place October 10–11 at UC Davis, assembled more than 200 K–12, higher education, industry, and nonprofit leaders and policymakers from throughout the state. Participants were engaged and enthusiastic, and generated more than 350 concepts and suggestions to spark innovation in STEM education (CSLNet 2011).

Lurking behind the collaborative panel discussions that gave rise to these ideas, however, were the grim statistics that had prompted the summit. Although in the 1970s California was a national leader in K–12 and higher education, in 2011 it ranked 34th among all states in math and science proficiency in grades 4 and 8 (White and Cottle 2011). The "golden dream"—which once propelled young students to careers of excellence in industry, academia, and politics—had become a tarnished waking nightmare (Provasnik et al. 2012).

This disturbing news isn't confined to California. The National Center for Education Statistics' 2011 *Trends in International Mathematics and Science Study* (TIMSS), published in December 2012, revealed the problem's international scope (Provasnik et al. 2012). The average math and science scores of US 4th grade students ranked them 11th and 7th, respectively, among the 57 countries and education systems that participated in the study. The situation is no better for US 8th grade students, whose math and science scores ranked them 9th and 10th, respectively.

But the rankings may actually obscure the *extent* of the achievement gap. Far more troubling is the fact that the average math score (509) of US 8th graders in 2011 showed no statistical improvement from the previous TIMSS, in 2007 (508), while countries such as the Republic of Korea, Singapore, and China/Taipei posted 2011 scores of 613, 611, and 609 (Gonzales et al. 2009; Killewald and Xie 2013).

With a mere one-point improvement over the course of four years—in the wake of No Child Left Behind—US students will never catch up. Indeed, they'll never get *close* to catching up.

A Link Between Algebra and Dropout Rates

Children are dropping out of school because of algebra (Helfand 2006) at a time when they are needed for the nation's economic security. A study from *Education Week* and the Editorial Projects in Education Research Center reported that 1.3 million high school students dropped out in 2010—roughly 7,200 per school day.[2] And according to a report prepared by the Massachusetts Department of Elementary and Secondary Education,[3]

- Dropping out of school impacts students' self-esteem and psychological well-being as they discover that they lack the skills and knowledge to fulfill their desires;
- Dropouts are 3.5 times more likely than high school graduates to be incarcerated during their lifetime; and
- Earnings for students who quit school continue to decline: in 1971, male dropouts earned an estimated $37,087, which decreased by 35 percent to $23,902 in 2002.

Furthermore, a recent survey commissioned by Raytheon revealed that 89 percent of middle-school students would rather do chores than math homework, and 33 percent would rather go to bed early![4] Since algebra is frequently taught in middle school, this finding may well apply to students' attitudes about this specific class.

Yet classrooms across the nation continue to teach algebra the same way it was taught in the 1950s and '60s. And since California legislators made algebra a statewide high school graduation requirement in 2004, more students are failing to graduate. A January 2006 *Los Angeles Times* article profiled one poor high school student who, over the course of six semesters, failed algebra six times. Midway through her senior year, she returned all her textbooks to the campus book room and left school for good (Helfand 2006).

"Repeated failure makes kids think they can't do the work," confirmed Andrew Porter, director of the Learning Sciences Institute at Nashville's Vanderbilt University. "And when they can't do the work, they say, 'I'm out of here'" (Helfand 2006).

Algebra isn't like the math courses that come before it. It is abstract, with variables instead of integers.

Why Is Algebra So Difficult?

Are the concepts of algebra truly harder than those explored in, say, fractions or percentages?

We believe the answer is yes.

Algebra isn't like the math courses that come before it. It is abstract, with variables instead of integers. Once letters are inserted for numbers, students get lost. The information must be presented to them in some other fashion.

Math is like a foreign language. It comes naturally to some people; others require lots of time and help. Some people need to see it in a context that makes sense to them in order to grasp it. It usually requires lots of practice.

[2] "Progress on Graduation Rate Stalls; 1.3 Million Students Fail to Earn Diplomas." Education Week/Editorial Projects in Education Research Center, June 20, 2010. Available online at www.edweek.org/media/ew/dc/2010/DC10_PressKit_final.pdf.

[3] The report, Dropout Reduction: Prevention, Intervention, and Recovery (updated Dec. 6, 2011), is available online from the Massachusetts Department of Elementary and Secondary Education (www.doe.mass.edu/dropout/); these statistics are from the Overview section on Consequences of Dropping Out.

[4] "Raytheon Inspires Students with New Virtual World of Math Via MathMovesU.com" (January 2008). Available online at www.prnewswire.com/news-releases/raytheon-inspires-students-with-new-virtual-world-of-math-via-mathmovesucom-57528972.html.

FIGURE 1 Professor Harry Cheng, Department of Mechanical and Aerospace Engineering, UC Davis, demonstrates an iMobot for participants in a summer youth camp session on robotics at the university. (Photo: UC Davis College of Engineering)

Students attempting to learn algebra confront many unique challenges (Rakes et al. 2010). First, algebra is often the first course where students engage in abstract reasoning and problem solving (Vogel 2008). Second, unlike basic mathematics—which deals solely with numbers—students must learn the language of mathematical symbols and the rules of arithmetic operations (Kilpatrick et al. 2001). Finally, algebra's structural characteristics can be too subtle for students who cannot, for example, recognize the difference between the expression $-x^2 + 5x - 6$ and the equation $-x^2 + 5x - 6 = 0$ (Carraher and Schliemann 2007; Howe 2005; Kieran 1992).

The interaction of the three fundamental concepts of algebra—abstract reasoning, the language of mathematics, and mathematical structure—is a formidable impediment for many students trying to master algebra (Rakes et al. 2010).

Innovative Approaches to Teaching Algebra

Although the PBS *NewsHour* segment presented the use of robots at King Middle School as revolutionary, it's by no means the only example of innovative teaching tools. Many schools around the country have used LEGO Mindstorms NXT to promote K–12 student learning of STEM (Crowley et al. 2003; Franz and Elmore 2009; Gale et al. 2007; Karp et al. 2010). The Los Angeles Unified School District has experimentally implemented a high school computer science curriculum with a full-year course that includes human-computer interaction, problem solving, Web design, robotics, computer applications, and an introduction to programming (Goode and Chapman 2009).

All of this comes as no surprise here at UC Davis, which is doing something quite similar . . . and it happened almost by accident.

Robotics

Dr. Harry H. Cheng came to UC Davis in 1992 as a robotics and computing researcher in the College of Engineering's Department of Mechanical and Aerospace Engineering. Since then he has earned numerous honors and awards, he regularly publishes journal articles and book chapters, and he has chaired or served as a guest speaker at dozens of conferences in the United States and China. Cheng and former graduate student Graham Ryland recently invented an intelligent, reconfigurable modular robot—dubbed the "iMobot" (Figure 1)—that earned a National Science Foundation Innovation Award grant and was featured in newspapers, magazines, and on television[5] (Anderson 2011).

The design of Cheng's iMobot technology is affordable, anthropomorphic, and modular, so it has an immediate appeal to a wide range of learners and serves as a launch pad for their imagination and creativity. In various classrooms, iMobots have been configured and programmed to represent dance troupes, soldiers, felines, vehicles, and even a barista. One robotic "game" involves projectiles: if a ball is shot from a specific point and a robot must be programmed to catch it, students must deal with variables relating to where the robot will be sent, the force and arc of the projectile, and so forth.

Tailoring Teaching for Today's Technology

Cheng has become most passionate about his outreach activities *outside* the lab. As director of the UC Davis K–14 Outreach Center for Integrated Computing and STEM Education (C-STEM), he has joined colleagues across the country in recognizing that the computing and robotics fields are ideal for engaging at-risk students in K–12 schools. His efforts initially highlighted robotics and computing, but he learned via teacher feedback that algebra was students' biggest problem, since they need to complete that course before moving on to computing. He therefore shifted his focus to help K–12 teachers present algebra in a manner that resonates with their students.

Cheng has come away with some strong opinions. "This is the 21st century, but some of the teaching methodology hasn't been updated with the times," he notes. "Teaching skill sets learned 30 years ago won't cut it; today's kids are too tech savvy for that."

The idea is to tailor the teaching curriculum for young students whose lives are consumed by smart phones, MP3 players, tablets, and all sorts of other technical gadgets. Cheng views his fields, computing and robotics, as a natural fit—a way to depart from rote pencil-and-paper exercises. And he's quick to clarify a key point: He's not talking about building new curricula, with more funding and fancy technology, solely for the benefit of top-tier students, most of whom arguably don't need such help. He worries most about at-risk students, the ones who often get left behind. He wishes to better educate *all* students, not just those who plan to attend college.

It's important to better educate all *students, not just those who plan to attend college.*

Programs for Teachers

Cheng's passion and innovative methodology have drawn the attention of the National Science Foundation, which in September 2012 awarded a pair of grants. The first, a two-year grant in the amount of $300,000, will help Cheng study collaborative mathematics learning—specifically algebra—with robots. The second provides $950,000 over three years to study how the use of robotics programs in schools can change students' attitudes toward STEM subjects. For his research in both these areas, Cheng and his co-investigators have recruited teachers from Sacramento-area schools, from grades 6 and up, and provided them with robots, teaching resources, and training.

The grants have allowed Cheng to expand programs he had already put in place. The Computing Research Experiences for STEM Teachers (CREST) project, inaugurated in 2011, was designed to create an enduring partnership between UC Davis faculty members and local secondary school STEM teachers, to help the latter guide their students toward further C-STEM studies and related careers. The program is supporting 45 computer science and STEM teachers—15 per year, for three years: 11 in-service teachers and 4 preservice teachers each year—as CREST Fellows. These individuals join Cheng for six-week summer programs, augmented by follow-up seminars and discussions that continue through the participating teachers' academic year. As a result, more than 30 schools from 20 districts in the greater Sacramento region have adopted the C-STEM research-based algebra and computing curricula, and roughly 1,500 K–12 students have benefited.

Clay Dagler, one of the participating instructors, has taught algebra at Sacramento's Luther Burbank High

[5] "Transforming Robots Not Just Science Fiction," ABC-TV Channel 7, San Francisco (May 12, 2011). Available online at http://abclocal.go.com/kgo/video?id=8130456.

FIGURE 2 Local high school participants at the UC Davis C-STEM Day, May 5, 2012. (Photo: UC Davis College of Engineering)

School since 1999. Now into his first revised academic year, Dagler already sees the results. "My kids are *jazzed* by the robots," he says, "which demonstrate how math is used, and where it goes in the future. The computer programming is engaging for them, because they can 'see' math in action. This isn't merely solving an equation on a page; students actually *work* the problem."

Competition

Ancillary "marquee events" include activities such as Robotics Academy competitions and the annual UC Davis C-STEM Day (Figure 2). At the C-STEM Day on May 5, 2012, middle and high school students showcased their skills in robotics and problem solving, while teachers, educators, and policymakers discussed how best to use computing, technology, engineering, and robotics in K–14 education. The third annual C-STEM Day, on May 4, 2013, featured two major activities: a RoboPlay Challenge Competition and a Math Programming Competition. The day concluded with an awards ceremony honoring achievement and excellence, along with scholarships for graduating students.

There are many such events across the United States: the FIRST Robotics Competition for high school students, the FIRST LEGO League Competition for students ages 9–14, the Junior FIRST LEGO League for students in grades K–3,[6] the VEX Competition for high school students,[7] and the Botball competition for middle and high school students.[8]

A Brandeis University evaluation of the FIRST Robotics Competition showed that participating students are more likely than the national average to attend a four-year university and major in engineering or computer science (Melchior et al. 2005). A workshop presentation on the Botball competition showed that participating girls became "significantly" more interested in robotics and STEM fields (Weinberg et al. 2007). Such studies clearly indicate that participation in robotics activities and competitions increases students' interest in STEM postsecondary study and careers.

Collaboration

Interactive programs offer a supplementary benefit: They expose children to the advantages of a shared, collaborative method of "working the problem," stimulating curiosity and facilitating long-term retention of the concepts. This is the desired result known as "deep learning," which actively engages students, often

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[6] FIRST (For Inspiration and Recognition of Science and Technology) is a national nonprofit program "founded in 1989 to inspire young people's interest and participation in science and technology" (www.usfirst.org).

[7] The VEX Robotics Competition is sponsored by the Robotics Education & Competition Foundation, which "seeks to increase student interest and involvement in STEM by engaging students in…robotics engineering programs across the US and internationally." Information about the robotics competition is available at www.roboticseducation.org/vex-robotics-competitionvrc/.

[8] "The Botball Educational Robotics Program engages middle and high school aged students in a team-oriented robotics competition" (www.botball.org).

collaboratively, in a search for relevance in their schoolwork. Deep learning promotes a level of long-term retention generally absent from traditional methods that are more apt to focus on memorization (Halpern and Hakal 2002; Millis 2010).

Additionally, collaborative learning tasks are effective because they encourage—even necessitate—contributions from each member (Cohen 1994), compelling participants to engage with the task *and each other* (Barron 2000, 2003). In other words, circumstances both require and allow for students to function effectively as a group, and thus more accurately mirror how STEM careers actually function in industry.

The Importance of Incentive

Incentive is another variable in the equation. Even now, in too many schools, passing algebra means only one thing: being “allowed” to take geometry. And passing geometry grants entry to Algebra II. That’s not much of a carrot; children must be captivated by *tempting* goals.

But even with hands-on relevance in the presence of robotics, algebra remains a wall to be climbed. Students must be encouraged to understand the exciting goals that await on the far side of that wall, which means opening a dialogue about future careers at a much earlier age.

Such dialogue is particularly crucial in populations where parents didn’t attend college, or where there is an absence of a supportive environment at home. Having such conversations early is important, because these students aren’t exposed to college—it’s not discussed in their homes, and they may not have relatives who went to college. Children need to be told about the possibility of additional, specialized education after high school and the benefits of pursuing such an education.

And yet such conversations aren’t integrated into today’s K–12 curriculum. Unless a good relationship exists between a local college and a school, students may not get that message.

Moving Forward

Although the feedback from Cheng’s middle and high school teacher-collaborators is encouraging, the results thus far are anecdotal, lacking the authoritative stamp of carefully tabulated results over time. For that reason, Cheng is working closely with research associates at the WestEd STEM Education Group to gather the hard data that will be necessary to build his local program into something larger. “If pilot programs are to be respected in the long term, and have a genuine impact,” says WestEd’s Jennifer Mullin, “you must have a good research agenda and plenty of data.”

But that takes time. The 854,000 new professional information technology jobs reported by the Bureau of Labor Statistics need to be filled *now*, and the number increases each year. Potential candidates for those jobs are already in middle or high school.

And yet the innovative, breakthrough—and *successful*—teaching methods being used at a few forward-thinking schools from Maine to California are still regarded as little more than pilot programs and novelties. They need to expand; they need to become national programs.

We at the university level—professors, department chairs, and deans—must become much more aggressive, much more vocal, in our demand that hidebound instructional techniques be replaced. We must insist on better preparation of students to fill college and university classrooms with engaged and resourceful undergraduates and postgraduates, who in turn will stimulate American tech industries that are desperate for inventive minds.

The few dozen K–12 teachers involved in such programs need to be given a stage from which they can share their results, so that instructors in classrooms across the country can experience the miracle of a once-failing algebra student who looks up one day and excitedly says, “I *get* this now!”

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It is time to move beyond tweaking the curriculum to a coherent, encompassing approach to the redesign of engineering curricula.

Undergraduate Engineering Curriculum

The Ultimate Design Challenge

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Two decades ago I witnessed a dramatic event unfold in engineering education. Believing that "real impact in engineering education will be made only by looking at the curriculum *as a whole*" (authors' italics, not mine), an engineering department at a major research university decided to engage in curriculum review and revision by taking what they called a "wipe the slate clean" approach (Director et al. 1995, p. 1246). At the time, I thought it a commonplace occurrence in higher education, or at least in engineering. But much of what has been done in the intervening years in engineering education, while promoting and deepening learning in specific courses and/or a specific year in the curriculum, has not in fact transformed engineering education across the country because engineering departments rarely take a "wipe the slate clean," holistic approach.

In this article, I highlight some of the most important findings from learning research that have been piloted and/or integrated into engineering courses or curricula around the country. These interconnected and interacting findings support the educational value of building curricula that provide

- context and continual integration across time and courses that promote transfer of existing knowledge and skills to new contexts;
- early exposure to engineering and engineers to lay the foundation for future learning;

- meaningful engagement at the most auspicious time to promote deep learning;
- opportunities for reflection to connect thinking and doing;
- development of students' metacognitive abilities to foster self-directed, lifelong learning skills; and
- authentic experiential learning opportunities to put theory into practice in the real world.

The work in engineering that has focused on the above is important, with results that have impacted learning, but because it is not coordinated or continual I question whether it is enough. I advocate the need to do all of the above *concurrently and continually across the curriculum*, in an intentional and coherent way, which may require a "wipe the slate clean" approach to the design of 21st century engineering education.

Context and Continual Integration Promote Transfer of Knowledge and Skills

For many instructors, the end goal of learning is the ability to use knowledge and skills flexibly in novel situations. Success in meeting this goal requires learners to transfer what they know to new settings or problems, which means first recognizing what is needed in a given context, then accessing and using the appropriate knowledge and intellectual skills.

Research (Glaser 1992; Simon 1980) shows that knowledge remains inert unless it is "conditionalized" (i.e., it includes conditions of applicability), and that students often don't use relevant information in problem solving because they don't recognize the need for it. Hence knowledge that is overly contextualized (e.g., traditional physics, chemistry, and calculus courses with "context-bound" examples) can impede transfer.

Conversely, when students are exposed to multiple contexts (think of a physics professor using engineering and architecture as well as physics examples to illustrate physics concepts), they are more likely to abstract relevant features, enabling them to recognize and use that knowledge flexibly in new contexts (Gick and Holyoak 1983). This research reinforces the notion that transfer is an active process of its own, and does not happen easily or automatically. It is essential to create a curriculum with the conditions and opportunities for transfer, as is being done at places such as California Polytechnic State University (Linda Vanasupa, California Polytechnic State University, email correspondence, January 15, 2013).

Of course, other aspects of context beyond integrating math, science, and engineering are important. For example, the social context of engineering involves understanding how the technical is shaped by the social and how much the technical can reshape the social (Adams et al. 2011). Teaching in this context is especially important to women and minorities as well as in battling the misconception of potential students and parents who view engineers as insensitive to social concerns (Vest 2011). A program at Worcester Polytechnic Institute (WPI) exemplifies the effort to address this concern: first-year students are engaged in solving complex technosocial problems under such broad categories as "Feed the World," "Power the World," and "Heal the World" (Tryggvason and Apelian 2012).

The end goal of learning is the ability to use knowledge and skills flexibly in novel situations.

Integration across contexts and over time is exactly what senior capstone courses are lauded for: They provide opportunities for students to make connections among ideas, approaches, experiences, and courses, and to synthesize and transfer what they've learned to new and complex situations. Yet leading engineering education researchers continue to voice concern that the current educational model is not effective in preparing engineering students to integrate knowledge, skills (and identity) as developing professionals (Dall'Alba 2009; Sheppard et al. 2008; Stevens et al. 2008). In other words, the senior capstone course is necessary but not sufficient in meeting the educational goal of integration.

Because integration and transfer are important components of deep learning,[1] students should be

[1]Deep approaches to learning—which result in long-term retention—require students to actively search for meaning (e.g., relating new information to their prior knowledge, organizing and structuring information meaningfully, looking for patterns and underlying principles, and engaging in self-explanation; Entwistle and Peterson 2004), whereas students who use surface approaches to learning focus on memorization, discrete elements, and the like.

continually engaged in these intellectual processes throughout the curriculum—not just in their final year—and at an increasingly sophisticated level. In fact, mastery requires students to acquire component knowledge and skills, practice them to the point that they can *combine them fluently*, and then *use them when and where appropriate* (Ambrose et al. 2010). Such continual integrative experiences help students to expand and deepen their "internal knowledge structure" of the discipline (i.e., organized networks of information stored in long-term memory), which will aid their eventual retrieval and use (Bransford and Schwartz 1999).

In short, very few undergraduate engineering programs provide courses each year (or at least activities within courses) that promote integration across context and time. A notable exception is the Olin College of Engineering, where students engage in "hands-on design projects in every year."[2] But why is this the exception and not the rule?

Introducing students to engineering and design in the first year leads to a powerful learning experience.

Early Exposure Lays the Foundation for Future Learning

I've established the importance of learning in context, and since many engineers engage in design, using that context to learn both knowledge and skills makes sense. A myriad of additional reasons explain why introducing students to engineering and design in the first year leads to a powerful learning experience.

First, research clearly indicates that students are more motivated to learn—*and thus engage in the behaviors that lead to learning*—when they see value in what they are being asked to do (Ambrose et al. 2010). Introducing them to the "big picture" of engineering and to "thinking like an engineer" can be motivating on several levels, including helping to show the relevance of the concurrent fundamental science and math courses they are taking.

Second, beyond learning the necessary technical aspects of engineering, students must learn intellectual skills, including the approaches engineers take as they engage in problem solving and design. The sooner students begin to approach their studies with the "habits of mind" that professional engineers engage in the better, because these intellectual skills can provide an overarching framework for the rest of the curriculum and cocurriculum.

Third, design projects in the first year get students into teams early (replicating "real world" engineering) and connect them with engineering faculty (Agogino et al. 1992). Finally, as mentioned, design projects that focus on the social impact of engineering work may address the problems of attracting more women and underrepresented minorities.

Engineering educators know that early design courses should focus more heavily on conceptual design methods and less on discipline-specific artifacts, as first-year students don't have the technical background to do the work (Dym et al. 2005; Kilgore et al. 2007). That is exactly what happened in one of the most notable and long-standing programs of this nature, which began at Harvey Mudd in 1955, where all majors were required to take project-based freshmen engineering design courses (Dym 1994). These courses were created to reinforce the notions that design is open-ended (hence several teams working independently and in parallel on the same project); that there are numerous engineering challenges beyond domains such as aerospace, computing, and manufacturing (hence sponsors of projects are broadly representative and include nonprofits); and that students could begin to think and work like engineers (hence introducing skills like structuring ill-structured problems, decomposing problems, identifying parameters and constraints, and working in teams).

Other universities followed suit, particularly in the 1990s and especially through some of the NSF-funded coalitions, and created first-year project and design courses "as a means for students to be exposed to some flavor of what engineers actually do while enjoying an experience where they could learn the basic design elements of the design process by doing real design projects" (Dym et al. 2005, p. 103).

[2] From the college's statement of vision on its website, www.olin.edu/academics/olin_history/vision.aspx.

With so much evidence supporting an early integrative approach to engineering education, why aren't these types of courses universal by now?

Meaningful Classroom Engagement Leads to Deeper Learning

A critical component of learning is deliberate practice coupled with targeted feedback (Ambrose et al. 2010); in fact, students learn what they practice and only what they practice. Yet this important learning activity is typically relegated to out-of-class time, ensuring that students do not get the immediate and constructive feedback they may need early in the learning process when the material is new, or when they are dealing with novel, complex problems. This lack of feedback has led, over many years, to the call for more in-class opportunities for students to practice and get feedback in real time from instructors and peers, a practice some call "pedagogies of engagement" (Smith et al. 2005). This type of pedagogy provides opportunities in class for students to apply concepts or principles, consider alternative approaches or designs, and engage in other learning activities that enable the instructor to detect and address errors in students' thinking.

While there are numerous effective ways to accomplish meaningful engagement during class, one of the most notable is the "peer instruction" strategy developed by Mazur (1997). In this model, after a short presentation, students are asked a conceptual question, given time to formulate and record their answer individually, discuss their answer with a peer, and, if necessary, revise their answer. This approach gets students talking about the problems, leading to deeper information processing, and enables peers and instructors to identify and address misconceptions on the spot and respond to gaps in understanding.

An equally effective and much used method in higher education, the case study, typically presents a realistic, complex, and contextually rich problem situation that requires connecting theory and practice (Barkley et al. 2005; Richards et al. 1995). If structured effectively, in-class case analysis provides an opportunity for analytical and integrative thinking with the added bonus of immediate feedback from peers and the instructor. There are examples from as early as the 1960s of case-based teaching and learning in engineering education (Raju and Sankar 1999; Yadav et al. 2010).

Finally, there are simulations, problem-based learning activities, collaborative and cooperative learning activities, the flipped or inverted classroom, and other classroom-based practices that can be done in real time to provide the same kind of practice and feedback opportunities as peer instruction and case studies (Prince and Felder 2006; Smith et al. 2005).

With so many sound examples of meaningful classroom engagement in engineering education publications and proceedings, why aren't such engaging activities embedded in every course across the curriculum?

Reflection Connects Thinking and Doing

When students engage in meaningful and frequent reflection about what they are learning, they are less likely to "have the experience but miss the meaning," because reflection provides a "continual interweaving of thinking and doing" (Schön 1983, p. 280). It generates, deepens, and documents learning (Ash and Clayton 2004). In fact, studies show that students who "repeatedly engage in structured reflection…are more likely to bring a strategic learning orientation to new challenges" (Eyler 2009, p. 28; Eyler and Giles 1999), reinforcing the end goal of learning as the ability to use knowledge and skills flexibly in novel situations.

Students learn only what they practice, and targeted feedback is a critical component of such learning.

There is no better way to get students to reflect on their learning than through writing. A rich literature focused on "writing to learn" (Fulwiler and Young 1982; Parker and Goodkin 1987) establishes the theoretical links among writing, thinking, and learning across a variety of disciplines. Embedding writing across the curriculum can help to promote deeper processing (enhancing students' ability to retrieve and use knowledge flexibly) by, for example, prompting students' reflection about what they are learning, how it connects to what they already know, and how they might use that knowledge in the future. Incorporation of reflection across the curriculum may be easier now because of the emergence of technologies such as e-portfolios (which allow students to assemble and showcase electronic evidence of their learning), which some institutions are using as a foundation for student reflection on their learning and performance; and it has indeed found its way into engineering education (Adams et al. 2003; Heinrich et al. 2007; Knott et al. 2004).

So, *yes*, students learn by doing, but only when they have time to reflect on what they are doing—the two go hand in hand. Why, then, don't engineering curricula provide constant structured opportunities and time to ensure that continual reflection takes place?

Metacognition Supports the Development of Lifelong Learning Skills

The vast majority of institutions of higher education in the United States articulate the need to prepare students to be lifelong learners so they can thrive in the current and future workforce. Numerous studies project the number of different jobs current students will have over their careers. Today's students will work in jobs that don't yet exist. Information quickly becomes obsolete. For all these reasons, it is essential to ensure that students can continue to learn independently, which requires engaging in metacognition, often defined as the process of reflecting on and directing one's own thinking (Bransford et al. 2000).

In-class engagement can provide an opportunity for analytical and integrative thinking, with immediate feedback from peers and the instructor.

The iterative cycle of self-directed learning requires students to engage in a number of processes:

- assessing the task at hand, including goals and constraints;
- evaluating their own knowledge and skills, including strengths and weaknesses;
- planning their approach in a way that accounts for the current situation;
- applying various strategies to enact the plan and monitoring their progress; and
- reflecting on the degree to which their current approach is working so that they can adjust and restart the cycle as needed (Ambrose et al. 2010).

This cycle might seem like "common sense" to many faculty members, but research reveals that, while experts engage in these processes, often unconsciously, novices do not (Ambrose et al. 2010). Furthermore, metacognition is rarely formally or explicitly addressed in courses or curricula. But students must be "quickly disabused of the notion that scientists and engineers work mostly on problems that can be solved using memorized facts and procedures" (Felder and Brent 2004, p. 283). They need to learn how to learn.

As noted above, reflection and writing can help students become more cognizant of their own learning process and can promote their ability to continue to learn throughout life (Ash and Clayton 2004). Again, a few engineering educators are exploring how to prepare students for lifelong learning (Heinrich et al. 2007; Jiusto and DiBiasio 2006), but why aren't all focused on this critical intellectual skill?

Experiential Learning Opportunities Connect Theory and Practice in Authentic Settings

Experiential learning is, simply put, learning by doing. As Eyler (2009, p. 28) notes, "theory lacks meaning outside of practice." Experiential learning naturally integrates theory and practice. And it happens in the classroom or lab (e.g., in design projects, capstone projects, case studies, simulations), although many would argue that it is much more powerful and robust when students have opportunities to use their knowledge and practice their skills in off-campus, real-world situations (e.g., co-ops, internships, service learning).

Furthermore, experiential learning opportunities prompt learning when students are put in unfamiliar situations for which they are not prepared and yet must act in order to get a job done. In other words, it provides practice in using self-directed learning skills and transferring what they know across contexts and over time to novel situations, as described above.

Over the past decade, because of increasing concern about the quality of higher education (Arum and

Roksa 2011; Bok 2006), scholars have sought to understand what experiences correlate to "the most powerful" learning outcomes (Kuh 2008).[3] They have used their data to call for, among other things, the design of more "high-impact courses" as well as "greater fluidity and connection between the formal curriculum and the experiential co-curriculum" (Bass 2012, p. 26). Bass (2012, p. 28) also suggests that the optimal way to learn is "reciprocally or spirally between practice and content," a reverse of typical curricula that are built from content and *eventually* engage students in practice. The best-case scenario, according to Bass (2012), is an educational environment that weaves the connections back and forth across the formal and experiential curriculum. This strongly speaks to experiential learning in general, and specifically to cooperative learning.

Experiential learning also enables university students to bring back and integrate into the classroom both the authentic applications of their knowledge and skills and the new knowledge and skills they have gained. Thus experiential learning not only strengthens and deepens what students already know and can do, but also provides an expanded platform for future learning. In short, experiential learning opportunities and formal academic programs can inform and complement each other.

Many engineering programs engage students in experiential learning activities such as co-op or service learning, and some engineering faculty members have tried to assess the impact of these experiences on self-directed, lifelong learning (Jiusto and DiBiasio 2006). The perceived value of such experiential programs is validated by engineering education research indicating that students see extracurricular experiences such as co-ops and internships as more representative of what it means to be an engineer than their in-class experiences, and they report a steep learning curve in their first job when this element is missing from their education (Korte et al. 2008).

Why should students wait until they enter the workforce to apply what they have learned?

[3] High-impact practices include undergraduate research, study abroad, service learning, internships, learning communities, and capstone courses. According to Kuh's research, these practices correlate with high retention and persistence rates as well as student behaviors that lead to meaningful learning gains.

Conclusion: Putting It All Together—A Systems Approach

The examples discussed here, and many more documented in engineering education journals and elsewhere, show that the engineering education community has accumulated a rich body of knowledge over the past 20 years and implemented many successful educational innovations that have had impact on student learning. Why, then, haven't there been major changes in engineering curricula and more students flocking to the field?

Students report a steep learning curve in their first job when hands-on extracurricular experience is missing from their education.

One answer is that we (faculty) rarely reflect on the larger context. Rather, we focus on what we have immediate control over, our courses. However, to effect significant change, we must redesign by leveraging and integrating *continually across the curriculum* the results of the solid work done by engineering education and learning sciences researchers. No one knows better than engineers the importance of systems thinking in problem solving and design, and yet much of the wonderful work that has been done in engineering education has focused on pieces of the curriculum rather than the whole of the curriculum and beyond. Since we operate in a dynamic system—that includes student expectations, faculty beliefs, departmental norms, college resources, university culture, societal needs, and global challenges—we must recognize that curricular change takes place in a broader context and requires, for example, faculty buy-in, departmental leadership, and necessary resources.

This brings me back to the story I alluded to at the beginning of this paper. Let me end with that experience and the main lessons I draw from it.

It was the Electrical and Computer Engineering (ECE) Department at Carnegie Mellon University that, in 1989, adopted a "wipe the slate clean" approach to curriculum review and revision, a two-year process that resulted in a radically different curriculum that proved to have many long-term advantages (Director et al. 1995). The transformative process first required recognition that "real impact in engineering education will be made only by looking at the curriculum *as a whole*" (p. 1246; authors' italics). It also required acknowledging that knowledge in the field of ECE was expanding rapidly, but the time to degree was not, so some difficult decisions needed to be made.

As a result, the new curriculum addressed some of the issues discussed above—for example, the need for students to (1) see the big picture, i.e., the connected view of the ideas that define the discipline; (2) integrate across courses rather than experience the curriculum as a set of discrete courses; and (3) come into contact with engineering faculty and engineering ideas during the first year. This revision resulted in, among other things, new courses at the freshman level and more flexibility for students in the curriculum (e.g., a smaller core of required classes, area requirements instead of course requirements, free electives). These were major changes, not minor tweaks. But more importantly, the approach spread to the entire engineering college as other departments followed suit.

Why is this story so instructive? First, it happened almost 25 years ago and, although a few other universities took a similar radical approach to reengineering engineering education both before and after CMU (e.g., Drexel, MIT), this type of revision has been the exception, not the rule. Second, such transformation required leadership and support at the department and college levels, as well as collaboration among the entire faculty because "everything was up for grabs." Finally, it took time and resources, provided by the department head (and when it spread to the college, the dean), which signaled the importance of the endeavor.

Where does this leave us in 2013? We have bold models (both old and new) to follow; we know a lot about how learning works; and what we know has been applied at a "micro" level to engineering education. It is time to move beyond tweaking individual courses or revamping one year of the curriculum. We need to be audacious enough to put the pieces together in a coherent, encompassing way across engineering curricula.

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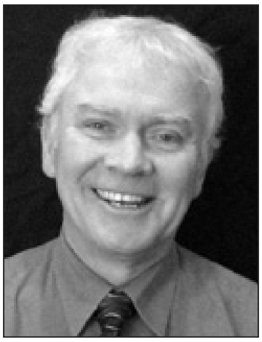
Engineering will be well served by creatively engaging students throughout their education to make engineering a positive and rewarding experience applicable to any field of study or profession.

Opportunities in Engineering Education
Pathways to Better-Prepared Students


David B. Spencer


George Mehler

David B. Spencer and George Mehler

Engineering is an integral part of daily life and can provide a strong foundation for almost any career path. Teaching about the wondrously engineered world and drawing on everyday existence for teaching examples can make learning fun and relevant. Yet engineering faces a number of challenges, many of them rooted in education:

- Engineering educational approaches are stale and need updating (Tryggvason and Apelian 2012).
- The proportion of US college graduates in engineering is low and dropping (NSF 2006).
- Dropout rates are much higher in engineering than in other areas of college study (Dodge 2008).
- Girls and young women do not see engineering as a pathway to multiple career choices (Wang et al. 2013).
- Engineering education at the high school level, let alone lower grades, is virtually nonexistent.

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Is it any wonder that most young students have misconceptions of engineering? Among critical factors to attract young students into engineering are:

- Training in math, science, and engineering, which should begin at an earlier age;
- Teacher training and new curricula to help students learn in a way that is fun and exciting; and
- Hands-on learning opportunities, such as field trips and camps that focus on science, technology, engineering, and mathematics (STEM), to show the value of engineering and correct misconceptions about both academic and professional engineering.

Doing these things effectively at the K–12 level should increase the number of high school students who pursue engineering in college—and afford them a glimpse of the social and monetary value of an engineering degree.

Student-Centered Education

How should engineering education change over the next 20 years? The practice of lecturing to impart knowledge should change to a model in which the teacher asks key questions and acts as a coach, and students develop their own individual learning program to address the questions, working alone or in groups.

Growing Interest in Student-Centered Education

In a great TED talk in 2010, Sugata Mitra, winner of the 2013 Ted Prize, argued that *teaching does not equal learning*. He has gone on to make a compelling case for the benefits of a "self-organized learning environment" along with "encouragement." His hypothesis is that the teaching curriculum should be one of asking questions, standing back in awe, and letting education happen, particularly in a small group environment. While his approach may not be fully appropriate for all aspects of future engineering education, it certainly provides much-needed food for thought about the effectiveness of past and present engineering teaching methods and practices.

An article entitled "The Efficacy of Student-Centered Instruction in Supporting Science Learning" (Granger et al. 2012, p. 105) cites numerous studies on the need for a different approach to teaching science, including one study by the National Research Council that synthesized research and suggested that

> the goal of science instruction should be to help students develop four aspects of scientific proficiency, the ability to (i) know, use, and interpret scientific explanations of the natural world; (ii) generate and evaluate scientific evidence and explanations; (iii) understand the nature and development of scientific knowledge; and (iv) participate productively in scientific practices and discourse. *This approach to science teaching will require a shift from the teacher-centered instruction common in science classrooms to more student-centered methods of instruction*. The defining feature of these instructional methods is *who is doing the sense-making*. In *teacher-centered instruction* the sense-making is accomplished by the teacher and transmitted to students through lecture, textbooks, and confirmatory activities in which each step is specified by the teacher. In these classrooms, the instructional goal is to help students know scientific explanations, which is only part of the first aspect of scientific proficiency. In *student-centered instruction*, the sense-making rests with the students, and the teacher acts as a facilitator to support the learning as students engage in scientific practices. [Emphases added.]

Learning can be practical, relevant, and fun.

Examples of Student-Centered Education

The Birches School in Lincoln, Massachusetts, dynamically incorporates STEM and art (thus "STEAM") in teaching grades K–2 (with the addition of a grade a year it will become a K–6 school). The Birches School children are learning math, biology, physics, chemistry, materials, computers, reading, and writing—all as an integrated knowledge base. They don't study individual subjects as such but rather learn them by working on their own and in small groups with the guidance and encouragement of their teacher.

This past winter, for example, the children decided they wanted to learn more about birds, so the teachers adjusted the curriculum accordingly. The children became "citizen scientists," part of ProjectFeederWatch administered by the Lab of Ornithology at Cornell University. They observed three bird feeders for 15 minutes a day on two consecutive days a week, counting and then graphing the number of birds of different species that they saw. They made scientific drawings of birds, measured wingspans, and learned from recordings the calls of various local birds. They dissected pellets spit up by owls to discover the fur and bones of ingested prey, then sorted the bones in categories, identified them, and mounted them. They each chose a bird to research, reading age-appropriate materials, and wrote a report and presented their findings to classmates. Finally, they created collages of birds and papier mâché birds.

Learning for the Birches School students is practical, relevant, and fun. Surely there is some wisdom in this program that could be applied to middle school, high school, and undergraduate engineering teaching methods.

At the undergraduate level, Worcester Polytechnic Institute (WPI) sets up three qualifying projects for students as they begin their studies (described in Tryggvason and Apelian 2012, p. ix):

- The interactive qualifying project (IQP) engages small teams of students in addressing complicated, broad-based problems of societal importance, many carried out in other countries;
- The major qualifying project (MQP) is essentially a team-based capstone project; and
- The sufficiency project demonstrates mastery of subject matter in the humanities and arts.

Students will pursue that which is fun to learn even if it involves significant hard work.

The approach at WPI encourages self-learning, working in teams, communication, and collaboration, in part by allowing students to choose a topic tied to perceived social needs.

Individual engineers, working in isolation through what might be called constructive dissonance or individual genius, may in some cases germinate better ideas than teams and foster pursuit of out-of-the-box approaches, but working in teams is extremely important in much of an engineer's professional life. Further, many students want a career that is both challenging and provides social interaction.

In short, engineering schools need to modernize their messages and their curriculum. If not, students will choose another field of study that seems more relevant and creates higher value for them. They will pursue that which is fun to learn even if it involves significant hard work.

National Standards and Opportunities to Introduce STEM in K–12

Very few young students are exposed to STEM, let alone engineering, at an early age. In the 20th century, most public and private schools in the United States focused on topics and skills that were important to their school or school district. Few states had developed standards for their schools, and on the national level there were no content standards that might help focus a K–12 program or particular courses. This lack of curricular focus meant that there was, and still is to a large extent, large variability in the content and skills that students are expected to master.

This situation started to change with the development of national standards—in mathematics (1989), English language arts (1996), and science (1996). Developed by experts and exceptional educators in each field, these standards were groundbreaking. But US education policy is set mostly by states and local school districts rather than by the federal government. So many schools did not adopt these standards, if they developed or used standards at all.

In 2001, the federal government passed the No Child Left Behind Act, requiring states to develop assessments in basic skills, establish levels of achievement, and assess students each year. In the absence of an established national level of achievement, each state was free to determine its own.

In 2009, the National Governors Association developed curricular standards for literacy (English language arts, or ELA) and mathematics, usually referred to as the Common Core standards. But there is an important difference from the earlier standards movement: this time 45 states have said they will adopt these standards. For the first time the United States will have a national set of education standards in ELA and mathematics.

But what about new *science* education standards?

Building on the Common Core movement, the National Research Council, with support from the Carnegie Corporation, is developing the Next Generation Science Standards (Schweingruber et al. 2013). Hopefully, states will adopt these new science education standards just as they have adopted the Common Core in ELA and mathematics. As a first step, the National Research Council released *A Framework for K–12 Science Education Standards* in July 2011. In December 2012 the NRC published *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, and in summer 2013 a consortium of states together with the American Association for the Advancement of Science and the National Science Teachers Association will release the actual standards.

One of the exciting additions to the new standards is, for the first time, the inclusion of engineering concepts and principles. The Next Generation Science Standards build on the three "core idea" areas—physical sciences, life sciences, and earth-space sciences—and add a fourth, engineering, technology, and the applications of science.

America's future leaders, pioneers, entrepreneurs, dreamers, and citizens need to understand the beauty, wonder, and power that are unleashed through experience and knowledge of science and engineering, and this understanding must start at a young age. The Next Generation Science Standards make engineering principles an important part of education for even very young students. This is an important breakthrough for engineering education.

The Internet and Open, Interactive, Personal Teaching Opportunities

If the new national standards are adopted (and at this point there is no certainty that they will be), there will remain other challenges in creating world-class science education in the United States.

Many schools provide little or no time for science education until students enter high school. A recent study of elementary science education in the San Francisco Bay Area—home to much US innovation in science and technology—reported that 80 percent of K–5 teachers spend 60 minutes per week or less on science, and that 16 percent of them spend no time at all on the subject (Dorph et al. 2007). In the same study, teachers reported feeling that they were ill prepared to teach science and had few opportunities to improve their preparation. Lesson plans and experiments are available on the Internet, and teacher camps exist, but more is needed.

Nurturing an interest in science early in life is important for students to learn about its wonder and beauty as well as opportunities and careers in science. But the necessary funding, teacher time, and training are not available. The engineering community needs to give thought and energy to how that can be changed.

Technology and expanded use of the Internet may help in efforts to address this problem. The past 10 years have seen an explosion of web tools for interactivity, collaboration, support, and individualized learning. So the Internet can change the playing field in a manner not possible in the past.

In particular, the Internet can be a source of free, research-based, high-quality professional development for teachers (free access is the best way to reach financially disadvantaged schools and teachers). Beyond scientific facts, teachers need a resource that shows them how to teach the skills, concepts, and practices of science and engineering, to enable students to understand what makes these fields different from other forms of human endeavor. Access to such learning also shows students that *everyone* can do science.

America's future leaders, pioneers, entrepreneurs, dreamers, and citizens need to understand the beauty, wonder, and power of science and engineering, and this understanding must start at a young age.

Many US schools have many hurdles to overcome—poverty, inadequate resources, collapsing facilities, lack of qualified teachers. Technology can help in one area: the delivery of world-class curricula and professional development for teachers, which they can learn in an asynchronous manner. The recent proliferation of MOOCs (massive open online courses) may help (evidence indicates that only about 10 percent of students complete these courses, but use of this educational resource is still in its early days).

Through the skilled use of open-source, interactive, and supportive technology the United States has the opportunity to empower teachers to improve their own capabilities and those of their students, including raising their level of science knowledge to meet the national standards. Such technology can—and should—be made available to all students and teachers, not just those that can afford it. But teachers will continue to be a critical influence on successful learning.

A recent ExxonMobil initiative called Let's Solve This reports on its website that research shows the importance of investing in teachers and concludes:

> If we want to improve our schools, what should we invest in? . . . [R]ecent research shows that nothing transforms schools like investing in advanced teacher education. . . . Let's invest in our teachers so they can inspire our students.

Properly trained and equipped teachers are needed as mentors, coaches, and encouragers. To paraphrase Rachel Carson (1965),

> If children are to keep alive an inborn sense of wonder, they need the companionship of at least one adult who can share it, rediscovering with them the joy, excitement, and mystery of the world we live in.

If better professional development can help more teachers become that "one adult," more children will understand science, the world, and their place in it.

Effective engineers can draw on their intuition to discern among fact, opinion, and motive to arrive at sound judgments.

Opportunities to Incorporate the Arts and Encourage Intuition

Engineers are human beings first and engineers second—or they should be. They must deal not only with the facts and laws of science and engineering but with people, so they must also have a sense of the arts, character, and positive purpose and integrity. They need sensitivity and empathy. They must be able to piece together sparse information, conflicting data, and distinguish truth from perception. With attention to people's facial expressions and intonations, effective engineers need to draw on their intuition to discern among fact, opinion, and motive to arrive at sound judgments. They need to appreciate that, although engineering examinations often require a single right answer, many real-world situations are characterized by shades of grey and may not have just one right answer. For all these reasons, engineering education should expand to include the arts and humanities—and respect for intuitive skills.

Philosophers through the ages have pondered the human liability to ignore intuition, resulting in decisions and actions guided by overrationalization—even in the knowledge that those decisions and actions are wrong. Because engineers' work—their decisions and actions—directly affects millions of everyday lives, it is crucial that they heed their intuition at every stage.

Those who have read the book *Blink: The Power of Thinking Without Thinking* by Malcolm Gladwell (2005) will understand how much faster the right brain can be at taking in data, both consciously and unconsciously, than the more deliberate left brain. Gladwell (2005, 265) observes that

> The key to good decision making is not knowledge. It is understanding. We are swimming in the former. We are desperately lacking in the latter.

Knowledge is the purview of the analytical left brain; understanding draws on the intuitive right brain to make sense of that knowledge.

We urge teachers to seek ways to incorporate intuition in their curriculum, as it is a critical characteristic of a fine engineer. In assembling and evaluating "big data," for example—where it is hard to know all the details, and the outcomes may not feel right even though the data and the processes or theories appear correct—it is important to heed one's intuition to perform "fallacy" checks. Attention to intuitive instincts can prevent big mistakes from big data.

Young engineers need to learn the arts, to trust their intuition, and to listen, in order to understand and artfully apply their engineering knowledge to solve the problems they confront.

Opportunities to Impart Good Character and the Freedom to Fail

The *New York Times*, in the Education issue of its magazine in September 2011, ran an article entitled "What if the Secret to Success Is Failure?" (Tough 2011). The article discussed the joint endeavors of two headmasters, one at a rich, white private school and the other at a low-income, largely black and Latino private school. Their goal was to get their students into top-tier colleges, keep them there, and prepare them for life. After looking at test scores, IQ, and the like, both headmasters concluded that what they needed in their curriculum was the "science of good character."

In seeking to define "good character," 24 character strengths were identified as important and common to all cultures and times. The list includes bravery, citizenship, fairness, wisdom, and integrity; emotional aspects such as love, humor, zest, and appreciation of beauty; traits related to social intelligence, described as the ability to recognize interpersonal dynamics and adapt quickly to different social situations; and kindness, self-regulation, and gratitude—values emphasized in many religious traditions.

What was so interesting in this article was that students who persisted in college were not necessarily the ones who had excelled academically. They were the ones with exceptional character strengths, like optimism and persistence and social intelligence. They were the ones who could recover from a bad grade and vow to do better next time and get extra help after class to improve.

> People who accomplished great things often combined a passion for a single mission with an unswerving dedication to achieve that mission, whatever the obstacles and however long it might take. . . . [T]his quality [is called] "grit." (Tough 2011)

The article goes on to observe that

> we have an acute, almost biological impulse to provide for our children, to give them everything they want and need, to protect them from dangers and discomforts, both large and small. And yet…what kids need more than anything is a little hardship: some challenge, some deprivation that they can overcome, even if just to prove to themselves that they can. (Tough 2011)

If they can, parents protect their children from experiencing failure for many reasons, but usually to be helpful and minimize their pain and suffering. But protecting students and children from failure does not make them smarter or stronger: it disables them and undermines their personal growth and the development of responsibility. Quoting one of the headmasters,

> The idea of building grit and building self-control is that you get that through failure, and in most highly academic environments in the United States, no one fails anything. (Tough 2011)

Thus the engineering student with a score of 800 on the math SAT and straight As in math and science may not be the best student for either academic success or long-term contributions to society. Academic skill must be enhanced by character and relationship skills. Deficiencies in both academic and human knowledge may be overcome through thoughtful education, hard work, and persistence.

It is easier to teach knowledge than it is to change someone's character. But a good engineer in the 21st century needs both.

Conclusion

Engineering faces serious challenges, and education is a pathway toward solving them, especially if new methods of teaching and learning are evaluated with an open mind.

The Next Generation Science Standards put greater K–12 emphasis on STEM and for the first time add engineering to a national education standard. As engineers, we should support implementation of these new standards at the state level and locally.

The Internet can contribute to cost-effective instruction for both teachers and students, but teachers play the most critical role in student learning through their encouragement, example, companionship, and knowledge.

Engineering education should train students to work effectively in groups, through collaboration and the development of interpersonal relationships. Good engineers also need to have character—integrity, social intelligence, and grit—and the ability to trust their intuition. These character traits and skills can be taught and learned through discipline, example, and opportunity, and will lead to more effective engineers with a more productive and fulfilling life.

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By working closely together, industry and academia can develop engineers who are not only technically strong but also creative and able to work well in teams, communicate effectively, and create useful products.

Aligning Engineering Education and Experience to Meet the Needs of Industry and Society

Rick Stephens retired in March from the Boeing Company as Senior Vice President of Human Resources and Administration.

Rick Stephens

Industry and society depend on engineers for the design and production of goods that meet customer needs and are safe, reliable, efficient, and competitive in the global market. Given the dynamics of the global economy and changing US age demographics (specifically, in this context, the large number of engineers approaching retirement), much has been written about whether there will be a sufficient number of engineers to meet industry and societal needs.

Furthermore, although colleges and universities produce technically competent graduates who understand engineering concepts and demonstrate the ability to apply them in the real world, they often lack the people skills (also called "soft" skills) that enable them to meet their full potential. Today's engineers need to be not only technically strong but also creative and able to work well in teams, communicate effectively, and create products that are useful in the "real world."

Industry, society, and engineering schools can—and should—collaborate to ensure a sufficient number of such qualified and capable engineers to meet industry and society needs. In this article I discuss measures to achieve these goals.

Engineering Education and Employment: Recent Facts and Figures

The road to an engineering degree has long been characterized by challenging courses, a heavy course load, long hours of study, and high failure rates. It was not uncommon for some of the best and brightest who entered engineering school to drop their pursuit of an engineering degree and move to an easier course of study. Some even dropped out of college altogether. In 2011 it was reported that 40–60 percent of science and engineering majors change their major because "it's just so darn hard" (Drew 2011).

Engineering graduates often lack the people skills (also called "soft" skills) that enable them to meet their full potential.

The good news is that, notwithstanding these facts and figures, the United States has actually seen a recent increase in the number of undergraduate engineering degrees. From 2003 to 2009 the annual number of engineers graduating from US colleges and universities remained relatively flat (degrees awarded rose by only 3,000 during those seven years, from 71,000 to 74,000; Yoder 2012). But in 2010 there was a jump of 4,000, to 78,000 new degrees, and in 2011 another jump of 5,000, to 83,000.[1]

Moreover, the unemployment rate for engineers is just 2 percent (Gearon 2012), even as the national rate has averaged 9 percent since 2009.[2] Even when national unemployment was nearly 10 percent, the unemployment rate for engineers peaked at 6.4 percent. In addition, the highest-paying salary for a new college graduate in 2013 is in engineering, with an average starting salary of $62,535 (up 4 percent from 2012) and starting salaries as high as $93,500 (NACE 2013). And since only 5 percent of all undergraduates complete an engineering degree (Newman 2012), there is substantial demand.

With low unemployment, excellent salaries, and rewarding work, why is industry concerned that there won't be enough qualified engineers to meet its needs? Why is it that many students see engineering as a difficult degree to achieve? And what can be done to address these concerns?

The Importance of Soft Skills

There are at least two significant areas for enhancement in engineering education to address the concerns cited above:

1. ensuring that engineering students can not only achieve their degree objectives but also apply their skills in the real world, and
2. increasing graduation rates for students pursuing engineering degrees.

It turns out that progress in both areas requires the development and use of soft skills. In fact, many in business have observed that the factors that improve graduation rates are the same as those that support success in industry.

There are few reports from industry that students don't have the right technical competency to succeed—the engineering school accreditation process has ensured the acquisition of technical competencies. Rather, engineering majors who fail in industry are those who have all the right technical competencies but not the soft or people skills to be successful. Specifically, they tend to lack the ability to work well in teams, communicate effectively, define problems, and consider alternative and creative solutions. They also tend to rely too heavily on digital tools in their efforts to develop solutions that can be delivered in the real world.

Four Measures to Develop Engineering Students' Soft Skills

To address the need for students to acquire soft skills, many engineering school deans have enlisted the help of industry and technology leaders to understand the factors associated with soft skill development. These deans have created an environment that fosters the development of students' soft skills through their work in teams, on hands-on projects, and in industry, all as part of an engineering curriculum that is already achiev-

[1] These recent dramatic increases correlate with general undergraduate enrollment growth that began early in the decade. After remaining flat at about 375,000 between 2003 and 2006, undergraduate enrollment in 2007 began a steady rise, with an average annual increase of more than 22,000 students, bringing total undergraduate enrollment in 2011 to 471,000 (Yoder 2012).

[2] Data from the Bureau of Labor Statistics, available online at http://data.bls.gov/timeseries/LNS14000000.

ing excellent results. Following are four examples of such measures.

Assignment of New Students to Cohorts

As mentioned, engineering students face the challenges of a demanding curriculum, long study hours, and a high course load. These are particularly daunting for first-year students, most of whom must also adapt to the challenge of being away from home for the first time and being responsible for more than just their academics.

One successful model for helping students not only cope but also thrive involves assigning a cohort of up to 50 students to an engineering professor, preferably one who teaches an engineering introductory course and is clearly interested in the students' success. The cohort provides an environment for students to develop relationships with others who are experiencing the same challenges, and it ensures that a professor monitors their progress and can quickly address issues that may arise. Early evidence indicates that students who have such additional oversight and support move from the at-risk population (at risk of quitting their engineering studies or of dropping out altogether) to successful first-year students.

Engineering Professors Teaching Mathematics and Physics

Two of the most challenging courses for new engineering students are the introductory mathematics and physics courses. Some colleges and universities have considered them "weed-out" courses for engineering majors. But as colleges are in a position to select the best and brightest students from the many who apply, courses designed to cut out underachievers are no longer warranted.

For most engineering students, understanding and applying mathematical concepts is critical to their success in the classroom and eventually in the workplace. (And as one with an undergraduate degree in mathematics, I also appreciate the elegance that the field can bring to engineering.) A number of engineering schools have enlisted engineering professors to teach mathematics and physics, using real-world engineering examples to translate mathematical concepts into practice. The approach is associated with significant improvement in student performance and thus better retention and degree attainment rates.[3]

[3] While some have claimed that ABET requires mathematics and physics to be taught by the professors from those fields, engineering deans who have adopted the approach of engineering professors teaching math and physics indicate that it has not affected their ABET accreditation.

First- and Second-Year Engineering Student Projects

Engineers want to solve problems. At many schools, however, the approach has been to use the first two years of the engineering curriculum to ensure that students have a solid foundation of concepts and practices before they get to solve problems.

Fortunately, colleges are finding that engaging first-year engineering students in hands-on projects bolsters retention and performance. One obvious option is the involvement of these early undergraduates in supporting graduate students and their projects. In addition, strong relationships in the community and with industry can provide opportunities to engage first-year students. For example, Columbia University works with the community to identify and define projects for first-year students, who work in teams to develop soft skills, are able to use their newly learned engineering tools, solve problems for "customers," and begin their transformation from student to engineer in a way that is very useful to industry.

The use of real-world engineering examples to translate mathematical concepts into practice significantly increases student success rates.

Internships

Like student projects, internships have become a critical tool for preparing students for the workforce. One model that is gaining traction is to work with students to line up internships after their second year in engineering school. Duke University makes it a point to meet with second-year students to ensure that they are taking the right steps to participate in an internship, and then discuss the experience with them afterward to get feedback on how it went.

For many students, an internship is their first real experience with industry and their first opportunity to see what it means to be a practicing engineer in the field they are pursuing. If the internship experience is good, then the student continues in the selected field of study.

If, however, an electrical engineering student decides after the internship to become a civil engineer instead, there is time to refocus her studies.

Internships are also an opportunity for colleges and industry to work closer together. Experience at the Boeing Company showed that those with internships are far more successful as employees. The internships also provide a way to observe potential employee performance as well as get real-time feedback from students. As a measure of Boeing's confidence in the benefits of these engineering internships, the company recently doubled the number available from 600 to 1,200.

Conclusion

The four measures described above are just a sampling of options, but colleges and universities where engineering school leaders and faculty have implemented them (or measures similar to them) have seen steady increases in student retention and graduation rates. For example, at Duke, Columbia, Olin, and the University of Southern California, 85 percent of entering engineering students graduate with engineering degrees—a dramatic improvement over the figures cited in the *New York Times* article (Drew 2011).

These schools show that creating opportunities for students to engage as engineers makes a huge difference in their graduation rates and ensures that they meet the needs of industry. Students with access to such program enhancements do not drop out because "it's so darn hard" because, although they face the same challenges as their peers in other college or university engineering programs, they receive critical support and early opportunities to develop both engineering and people skills.

The key to ensuring that engineering graduates are ready for the future rests in how they are educated, which must involve more than the right technical content. An effective education in engineering must also include development of soft skills. Programs that cultivate both demonstrate high retention and graduation rates that also ensure students become employees that design and help produce goods that are safe, reliable, efficient, and competitive in the global market. Industry and engineering schools working closely together with students in a true partnership make it happen.

These are great examples and a strong start, but there is more to do. Tracking and reporting (1) the number of internships that businesses provide and (2) engineering school retention and graduation rates will go a long way toward enhancing accountability and continuing to achieve the results needed for US engineering students, industry, and the national economy.

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Students in entrepreneurship programs gain insights into designing for end users, working in and managing interdisciplinary teams, communicating effectively, thinking critically, understanding business basics, and solving open-ended problems.

Entrepreneurship
Its Role in Engineering Education

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It is an exciting time to be an engineer. In recent decades, the engineering workforce has helped the United States make substantial advances in communications, health, defense, infrastructure, and manufacturing (Blue et al. 2005), and the time between the emergence of new technologies and their implementation has steadily declined (Kurzweil 2001). Opportunities and challenges continue to require engineers to literally invent the future by developing breakthrough technologies that solve global problems and enhance the quality of life.

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Ongoing innovation is required to address pressing problems and to maintain America's global competitiveness, and engineering is the foundation of much of that innovation. To be prepared to enter the workforce and thrive in this ever changing global economy, engineers need to be able to collaborate effectively as leaders, in teams, and with their peers. In addition to their technical and analytical expertise, they need to be flexible, resilient, creative, empathetic, and have the ability to recognize and seize opportunities (NAE 2004; Sheppard et al. 2008). All of these skills can and should be taught to engineers as part of their formal education. It is thus the responsibility of engineering educators to instill these qualities in students to enable them to be more innovative and entrepreneurial.

It is the responsibility of engineering educators to teach their students to be more innovative and entrepreneurial.

In this article, we examine the importance of entrepreneurship efforts in engineering education, national support for entrepreneurship, student and faculty attitudes and engagement, noteworthy programs, and early research on these initiatives. We then offer our perspective on the future landscape for innovation and entrepreneurship in engineering education.

The Importance of Entrepreneurship Education

It is no longer enough to come out of school with a purely technical education; engineers need to be entrepreneurial in order to understand and contribute in the context of market and business pressures. For engineers who start companies soon after graduation, entrepreneurship education gives them solid experience in product design and development, prototyping, technology trends, and market analysis (Nelson and Byers 2010). These skills are just as relevant for success in established enterprises as they are in startups; students with entrepreneurial training who join established firms are better prepared to become effective team members and managers and can better support their employers as innovators.

Entrepreneurship education teaches engineering students in all disciplines the knowledge, tools, and attitudes that are required to identify opportunities and bring them to life. Students who take part in entrepreneurship programs as undergraduates gain insights not available from traditional engineering education, such as understanding and designing for end users ("empathy"), working in and managing interdisciplinary teams, communicating effectively, thinking critically, understanding business basics, and solving open-ended problems (ABET 1995; NAE 2004).

Expanding Support for Entrepreneurship

In many universities, entrepreneurship is no longer confined to business schools. In fact, it is one of the fastest growing subjects in undergraduate education overall, with formal programs such as majors, minors, and certificates quadrupling from 1975 to 2006 (Brooks et al. 2007).

And interest in entrepreneurship extends beyond higher education. In recent decades, technology entrepreneurs have become American heroes, and the entrepreneurial process has been embraced as a key element of the country's future success and global leadership. The White House has emphasized entrepreneurship as a means of driving innovation: in addition to improving STEM education, President Obama's strategy for American innovation calls for an investment in high-growth and innovation-based entrepreneurship to drive the US economy (NEC 2011).

The National Science Foundation has also invested in entrepreneurship and innovation with programs such as Innovation Corps (I-Corps), which prepares scientists and engineers to consider broader opportunities for their technology and research, and the National Center for Engineering Pathways to Innovation (Epicenter). Managed by Stanford University and the National Collegiate Inventors and Innovators Alliance (NCIIA), Epicenter was established in 2011 to expand the infusion of entrepreneurship into undergraduate engineering education. It sponsors initiatives that inspire engineering students to envision possibilities and create viable, innovative products, services, and processes.[1]

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[1] Information about Epicenter programs and resources is available online at http://epicenter.stanford.edu/.

Student and Faculty Attitudes toward Entrepreneurship Education

Unlike other changes to the engineering curriculum that have been implemented with little student input, there is substantial and growing student demand for entrepreneurship education. In an annual survey of American college freshmen, 41 percent of respondents said that "becoming successful in a business of my own" is an objective they considered "essential" or "very important" (Pryor et al. 2012). In a study of engineering students by Duval-Couetil and colleagues (2012), two-thirds of the respondents agreed that entrepreneurship education would broaden their career prospects and choices.

Among faculty and administrators, according to a recent ASEE survey, about 50 percent of respondents reported that access to entrepreneurship programs is important for their engineering undergraduates (Peterfreund 2013). While this might be interpreted as a discouraging statistic for the expansion of entrepreneurship in education, we view it as an opportunity.

Working with faculty members will help the Epicenter team understand their points of view and give us tools for influencing others. For example, it may be that some faculty members do not have experience in entrepreneurship and do not really understand it (Zappe et al. 2013). For others, it may be that their perception of their students' needs and challenges puts entrepreneurship low on the priority list of learning objectives. Furthermore, survey findings suggest that faculty perceptions about overcrowded engineering curriculum, and their belief that faculty peers and administrators are unsupportive of including entrepreneurial learning objectives in engineering education, contribute to making these objectives a low priority for engineering undergraduate programs (Peterfreund 2013).

Both in and outside the classroom, learning to be an entrepreneur requires a complex set of knowledge, skills, and abilities (Nelson and Byers 2010). The recent work of Zappe and colleagues (2013), which examined the beliefs of faculty who teach entrepreneurship to engineering students, is a first step toward understanding faculty perspectives on entrepreneurial skills and codifying, organizing, and advancing engineering undergraduate entrepreneurial learning objectives. Their study found that educators who teach entrepreneurship to engineering students believe that:

- The defining characteristic for an entrepreneur is the ability to act on opportunities. Other key characteristics are drive, passion, resourcefulness, and the belief that one can be successful.
- The characteristics of an entrepreneurial mindset can be learned, including the ability to act on opportunities, learn from failures, and solve problems, as well as technical, business, interpersonal, and communication skills.
- The way educators teach entrepreneurship is deeply influenced by their own career experiences as well as their beliefs about how people become entrepreneurs.

Understanding the beliefs of those who currently teach entrepreneurship is useful in defining the educational outcomes for entrepreneurial learning. These beliefs also suggest that more work is needed to enhance understanding of the relationships between teaching strategies, personal experience with entrepreneurship, and effectiveness in achieving learning outcomes.

About half of faculty and administrators report that access to entrepreneurship programs is important for their engineering undergraduates.

Faculty Engagement and Impacts

The integration of entrepreneurship and innovation in engineering education will require a shift in thinking and willingness on the part of faculty to participate in, or at least accept changes in, the engineering curriculum. Recent experiences in introducing new approaches to engineering education are a good indicator of the challenges and a guide to which approaches will be effective.

In a study of adoption of several major educational innovations in engineering education, Borrego and colleagues (2010) found that a combination of approaches was needed to build awareness, support practical adoption, and enable institutionalization. Developing well-defined and proven materials is necessary but not sufficient. Best practices and training opportunities need to be complemented by awareness and buy-in among faculty and administrators, and the provision of resources and incentives for implementation. Importantly, the highest adoption rates were found for innovations that could be implemented by individuals or small teams without a great deal of departmental coordination.

Engaging traditional engineering faculty is, however, only part of the picture, since many of those who teach entrepreneurship are clinical, adjunct, or nontraditional faculty. Therefore, curricular and noncurricular program development needs to take account of the advantages and challenges in terms of a school's faculty makeup.

Models of Engineering Entrepreneurship Education

A mixture of approaches to entrepreneurship education is necessary to deliver the experiences and knowledge that lead to innovative and entrepreneurial graduates. Fortunately, with high interest in entrepreneurship among students, there is an opportunity to catalyze student awareness and interest through short, engaging experiences. To that end, Epicenter is building on the success of NCIIA's Invention to Venture workshops by training and deploying "student ambassadors" at a number of institutions, where they hold events, run competitions, and exemplify the path toward becoming an innovator.

Successful student innovators become powerful role models for their classmates.

Also key will be thinking in new ways about how to approach entrepreneurship education. Some engineering schools have formal certificate and minors programs in entrepreneurship for their undergraduates, and 50 percent of faculty respondents to the ASEE survey reported that extracurricular programs are a prevalent means for engineering students to gain experience in entrepreneurship (Peterfreund 2013). The proportion of students participating in these experiences is still small, but their impact on the participating students and in inspiring their peers is important. Successful student innovators become powerful role models for their classmates.

Neck and Greene (2011) call for expanding concepts of teaching entrepreneurship from a process-based approach with known inputs and outputs to a methods-based approach that supports iteration and creativity. Others are thinking about the incorporation of entrepreneurship modules in which engineering problem solving takes place in the context of a business opportunity.

The emergence of online learning resources has been particularly useful for delivering digital content both in and out of the classroom. For instance, the Stanford Technology Ventures Program's Entrepreneurship Corner (ECorner) offers thousands of video clips that are easily incorporated in classroom discussions, student research, and presentations. Epicenter is building on the success of ECorner and creating small learning modules with entrepreneurship-related content. Online courses on entrepreneurship also allow faculty and students far removed from vibrant entrepreneurial ecosystems to access a wide range of instructors and content, and enable faculty to spend more time nurturing innovation.

Another high-impact approach involves creating intensive entrepreneurship programs and experiences for highly motivated students. Successful examples include the University of Texas at Austin's Idea to Product (I2P) competition, the NCIIA's E-Team program for launching student ventures, and a growing number of entrepreneurship-themed "living-learning" communities (combining student residence with curricular and extracurricular activities) at universities around the country (Inkelas et al. 2008). Students report that these programs put their engineering education in context and provide opportunities to learn about leadership in emerging and existing enterprises.

It is also important to explore commonalities between entrepreneurial skills and ABET guidelines to see how entrepreneurship can fulfill key ABET requirements. Alignment with these requirements can influence university leaders who are motivated to maintain their ABET accreditation.

Analysis of Existing Programs

A number of engineering schools have already made significant investments in programs to help their undergraduate students become skilled in entrepreneurship, and the recent work of Besterfield-Sacre and colleagues (2011; Shartrand et al. 2010) is an important step toward comprehensive analysis of such courses and programs in the United States. Their preliminary study found that the primary differentiators among these programs are "density of offerings" (coursework, extracurricular activities, minors/certificates, concen-

[2] The Carnegie Classification tracks institutional diversity in US higher education. Information is available online at http://classifications.carnegiefoundation.org/.

trations, and entrepreneurship majors), Carnegie Classification,[2] and physical and virtual spaces dedicated to entrepreneurial activities (incubators or business accelerators, web portals for campus resources, entrepreneurship research institutes, and design and prototyping spaces).

Building on this research, Epicenter has launched a study of 41 engineering schools that offer certificates or minors in entrepreneurship. The schools range in size from very small (13 engineering bachelor's degrees per year) to large (more than 1,700 such degrees). Some programs are housed in the engineering department or school (e.g., University of Pennsylvania), some are offered by the business school to students across the entire campus (e.g., University of Connecticut), and still others are partnerships between departments such as engineering and business (e.g., Rensselaer Polytechnic Institute).

A primary aim of the Epicenter study is to develop a multifaceted analysis of these offerings as a resource. Those who are designing entrepreneurship programs will be able to build on the models and experiences of others and to engage the larger engineering education community in discussions about how and why to include entrepreneurship in engineering education.

Looking Ahead

There is reason to be optimistic about the potential for infusing opportunities for entrepreneurship and innovation into engineering education. The NSF, NAE, and other engineering education supporters have invested significantly in spurring innovation in engineering education, and a growing field of engineering education researchers is studying and documenting what works, how, and why. Coupled with a well-supported approach that empowers faculty across the nation and engages both institutional leaders and accreditation bodies, this change is under way.

To continue building a movement to create more entrepreneurial engineers, we urge stakeholders in undergraduate engineering education to consider the following questions and actions.

Students: Ask questions of your professors, administrators, and fellow students. Where does entrepreneurship fit into the educational picture at your school? What opportunities already exist for you? How can you help build more opportunities?

Engineering faculty: Consider the role of entrepreneurship in all facets of your work, from teaching to research. How might the subjects you teach connect to engineering and business practice? How might your students benefit from seeing this larger context for their technical learning?

Academic administrators: Talk with your faculty, students, and alumni about their attitudes about entrepreneurship. How have elements of entrepreneurship and innovation added to their professional success? How might additional training in these elements contribute to future success?

Industry leaders and representatives: Reflect on how your operations use engineers with an entrepreneurial approach and mindset. How can you engage academic program faculty in discussions about the key entrepreneurial skills and abilities you need in your engineering workforce?

Beginning these conversations with your peers and other stakeholders can expose connections between motivated individuals and groups and yield opportunities for expanding the innovative and entrepreneurial ecosystem at your institution. With the growing support of entrepreneurship in the engineering community, we are confident that 21st century engineering graduates can and will be equipped with the ability to address the challenges of the coming decades in innovative and economically generative ways.

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The open education (OE) movement provides new mechanisms to democratize education by interconnecting ideas, learners, and instructors in new kinds of constructs that replace traditional textbooks, courses, and certifications.

Opening Education

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Richard G. Baraniuk

The clamor surrounding the high cost, limited access, static nature, and often low quality of the world's education systems is reaching a crescendo. Many observers claim a serious threat to the future of youth, the training of workforces worldwide, and even the democratic process. In addition, education is out of reach for many in the developing world, widening the gap between rich and poor people and countries.

The statistics are alarming. As Figure 1 shows, since 1978 textbook costs in the United States have risen 812 percent, more than three times the consumer price index (Perry 2012). No wonder that US student debt has topped $1 trillion and that a recent California study found that 7 out of 10 college students now choose not to purchase textbooks (Redden 2011). Adjusted for inflation, tuition costs at US colleges rose over 25 percent in the past decade. Besides cost, there is also the challenge of inadequate educational facilities. At a South African university in 2012, 11,000 desperate applicants vying for 800 openings induced a stampede that left one person dead and 22 injured.

Now imagine a world that has forestalled this crisis: a world where textbooks and other learning materials are free for all on the web and low-cost in print, adapted to many backgrounds and learning styles, interactive and immersive, translated into numerous languages, continually updated and corrected, and never out of print. A world where computers assist in teaching so

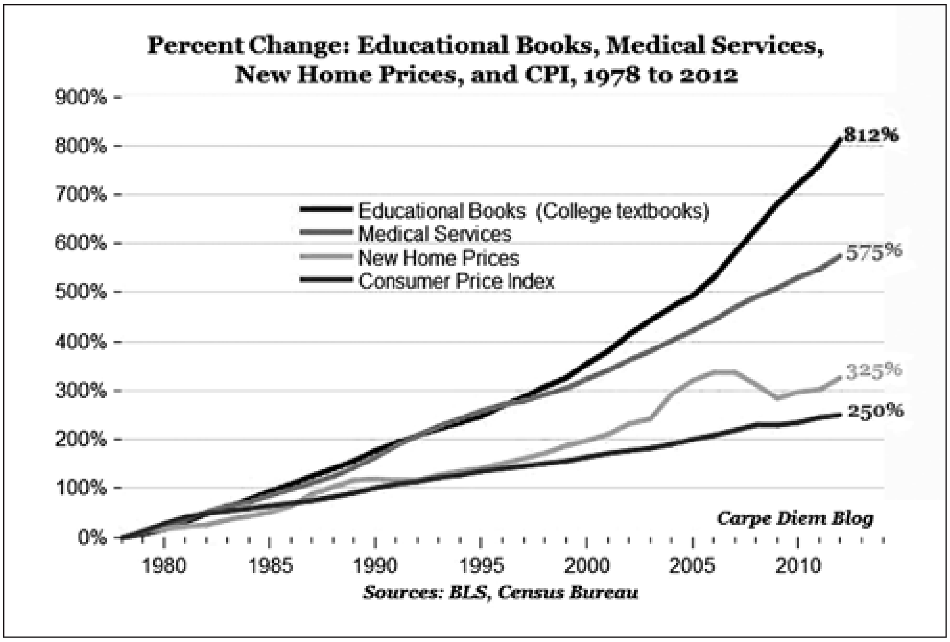

FIGURE 1 Percent changes from 1978 to 2012 in three Bureau of Labor Statistics' consumer price index (CPI) categories—educational books and supplies, medical services, and an aggregate of all goods and services (designated Consumer Price Index in the graph)—as well as the median price for new homes from the Census Bureau. Since 1978 textbook costs have risen more than *three* times the average increase for all goods and services. Reprinted with permission from Perry (2012).

that instructors can spend more time teaching concepts and values, giving insights, and providing inspiration. A world where courses can be taken from anywhere at any hour of the day or night. A world where a student study group encircles the globe. A world of "living" (i.e., constantly updatable) certifications and degrees that continuously document students' and lifelong learners' accomplishments.

While this world was just a dream even a decade ago, the open education (OE) movement that aims to create it is coalescing and gaining momentum. The movement is based on a set of intuitions shared by a remarkably wide range of academics and students: knowledge should be free and open to use and reuse; collaboration should be easier, not harder; and people should receive credit for what they've learned and demonstrated.

The OE movement is rapidly gaining momentum because of a "perfect storm" comprising two converging factors. First, the global financial downturn is forcing education systems worldwide to dramatically reduce costs on every front by updating their business models. Second, powerful telecommunication and information technologies are providing new, cost-effective ways to distribute content, support personal interactions, and store information.

In this article I describe developments on four fronts that promise to reinvent the way educators produce and disseminate educational materials and fundamentally change students' relationship with content. These four "frontline" areas are textbooks, courses, personalized learning, and certification.

While the timescale of education transformation has until now been measured in decades, even centuries, OE has the potential to radically alter the way authors, instructors, and students interact worldwide virtually overnight.

Open Textbooks

The textbook was the answer to the educational challenges of the 19th century, but it is the bottleneck of the 21st century. The textbook of today is static, linear in organization, time-consuming to develop, soon out of date, and expensive. Moreover, it provides only "one-size-fits-all" learning that doesn't cater to the background, interests, abilities, and goals of individual students.

Open Educational Resources

Communication and information technologies provide a golden opportunity to reinvent the textbook. Open educational resources (OER) include text, images, audio, video, interactive simulations, problems and answers, and games that are free to use and reuse in new ways by anyone around the world. The key elements of OER are:

- *open copyright licenses*, like those of Creative Commons, that turn educational materials into living objects that can be continuously developed, remixed, and maintained by a worldwide community of authors and editors; and
- *information technologies*, like the Internet and web, that enable easy digital content reorganization and virtually free content distribution.

The OER approach to textbooks has several important benefits:

- It brings *people* back into the educational equation. Those who have been "shut out" of the traditional publishing world—talented K–12 teachers, community college instructors, and scientists and engineers in industry—can add tremendous diversity and depth to the educational experience.
- It reduces the high *cost* of teaching materials. In many states, college students now spend more on textbooks than tuition.
- It reduces the *time lag* between the production of learning materials and their delivery to students. Many books are out of date by the time they are printed. This is particularly problematic in fast-moving areas of engineering, science, and medicine.
- It enables *reuse*, recontextualization, and customization such as translation and localization of course materials in myriad languages and cultures. This step is critical for reaching the entire world's population, where clearly one size does not fit all for education.

"Connexions" at Rice University

Several OER projects are already attracting millions of users per month. Some, like MIT OpenCourseWare (ocw.mit.edu), are top-down-organized institutional repositories that showcase their institutions' curricula. Others, like Wikipedia, are grassroots organized and encourage contributions from all comers.

In addition, there is Connexions (cnx.org), which I founded in 1999 with three primary goals: (1) to convey the interconnected nature of knowledge across disciplines, courses, and curricula; (2) to move away from a solitary authoring, publishing, and learning process to one based on connecting people in open, global learning communities that share knowledge; and (3) to support personalized learning (more on this below). Connexions has grown into one of the largest and most used OER platforms—each month millions of users access over 20,000 educational "building blocks" and 1300 e-textbooks (as of April 2013). In addition to web and e-book outputs, a sophisticated print-on-demand system enables the production of inexpensive paper books for those who prefer or need them, at a fraction of the cost of books from a conventional publisher.

Content contributions come from all over the world in more than 40 languages, including Spanish, Chinese, Vietnamese, and Afrikaans. In South Africa, Siyavula (cnx.org/lenses/siyavula), a nonprofit resource for technology-powered learning based in Cape Town, is developing a complete K–12 curriculum. Vietnam is using Connexions as a faculty development tool (voer.edu.vn). Professional societies such as the IEEE are advancing their global educational outreach and inreach through content development and peer review (ieeecnx.org; Kelty et al. 2008). Indeed, because the Connexions founders and early adopters were signal processing faculty and IEEE members, there is a strong extant signal processing foundation to build on.

To help busy college instructors adopt OER and save students money, Connexions recently partnered with a consortium of philanthropic foundations to launch OpenStax College (openstaxcollege.org) to provide free textbooks for today's highest-impact college courses. Textbooks are authored by professional domain experts and peer reviewed by practicing college instructors, and the library also offers lecture slides, image libraries, and test banks.

Open educational resources (OER) include text, images, audio, video, interactive simulations, problems, and games that are free for anyone to use.

The initial reaction to the project has been very positive. As of April 2013, more than 150 institutions had formally adopted the library's *College Physics*, *Introduction to Sociology*, *Biology*, and *Concepts of Biology* texts. *College Physics* now exceeds 3 percent market share. On an annual basis, more than 23,000 students are saving more than $2.3 million. When completed, every year the initial 25-book OpenStax College library will benefit over 1.2 million students at a 10 percent market share, saving students an estimated $120 million. Compared to the philanthropic investment required to build the library, the return on investment in terms of student savings is approximately 600 percent per year. And a number of planned translation/localization projects aim to make a further global impact.

Open Courses

A student transported from 1900 to the present would feel quite at home in one of today's typical lecture courses. Lectures remain a primarily passive experience of copying down what an instructor says and writes on a board (or projects on a screen). Such "teaching by telling" is effective for conveying information, but ineffective for imparting knowledge and actively engaging students.

Communication and information technologies make it possible to do much more. Schools have offered distance learning courses for decades. New technologies now make it straightforward to replace in-person lectures with YouTube videos, paper-based homework with web pages, and graders with computer algorithms. OE is taking the concept even further by opening access to any student, anywhere.

The Khan Academy (khanacademy.org) advanced OE by demonstrating the power of freely distributed short (10-minute) videos of mini-lectures and worked problems, thus enabling students anywhere to learn a new subject, solidify their understanding, or clear up their misconceptions. Moreover, the videos enable teachers to "flip the classroom" by having students view the lecture materials online on their own and then using valuable class time to discuss and work problems. The flipped classroom aligns with the philosophy of Confucius, who famously remarked: "I hear and I forget. I see and I remember. I do and I understand."

Massive online open courses (MOOCs) open up access by transporting lectures, examples, homework, tests, and office hours to the web.

Massive open online courses (MOOCs) take this concept a step further by transporting *all* the components of a course—not just lectures and examples, but also homework, tests, and office hours—to the web and opening up access to all. The canonical success story of a MOOC is Stanford University's fall 2011 Artificial Intelligence course that enrolled over 160,000 students from 190 countries. Volunteers translated it into 44 languages, and more than 23,000 students completed the course. Adding a human element to the course, thousands of study groups formed spontaneously via social networking sites, some grounded locally and others distributed globally.

The success of this initial experiment spawned a menage of educational MOOC enterprises, such as the for-profit Coursera, Udacity, and Google CourseBuilder and the nonprofit edX and Class2Go. A related enterprise is TED-Ed, a new education arm of the successful TED franchise that enables the remix of video lectures (not unlike the work of Connexions with textbooks).

Like OER, MOOCs democratize access to high-quality learning experiences and provide a large and widespread potential audience for enterprising instructors. They also enable students to form long-lasting social bonds with students from around the world, which bodes well for the increasingly global economy. The ability to replay online course material as many times as needed makes it possible to move away from competition in education (competition for access to courses, for the instructor's time, against each other due to curve-based grading) toward a world where everyone eventually masters the material and gets a good grade. Finally, MOOCs and other online courses will afford an unprecedented opportunity to observe and analyze student learning experiences, and the resulting quantities of data can be used to improve and eventually personalize the learning process.

Personalized Learning

At all levels of education, students typically receive instruction and activities as a group, regardless of differences in aptitude, prior knowledge, motivation, or interest. This one-size-fits-all approach forces students into artificial timelines for learning that often cause them to become bored or fall behind. Recent advances in technology provide the opportunity to revolutionize education by gathering data on student learning interactions and using the information to tailor instruction and activities to the needs and characteristics of each student in order to maximize learning outcomes.[1]

Limited but promising progress on computer-based personalized learning has built on a *content-centric* approach in which human domain experts tease apart

[1] Such personalized education is one of the NAE's Grand Challenges for Engineering (www.engineeringchallenges.org/cms/8996/9127.aspx).

and exhaustively encode (using ontologies, rule-based systems, etc.) the relationships among content, concepts, misconceptions, problems, solutions, and potential feedback in a subject. Although successful, this approach to facilitate learning has been extremely difficult to realize without major investments of time, money, and expertise. For instance, my discussions with a number of commercial providers of personalized learning systems have revealed that developing a single personalized learning course requires a multimillion-dollar investment and several years of work by disciplinary specialists. Progress in this area will entail not only lowering the costs and complexities of developing personalized learning systems but also increasing their range beyond that provided by hand-coded rules.

A promising alternative to the content-centric approach to personalized learning is a *data-centric* approach. In contrast to the years needed for humans to estimate how an individual student *might* interact with the content, a data-centric personalized learning system gathers data from *actual* learner interactions with the content and uses the data to tune the presentation and feedback to students. For the last four years, I have led a multidisciplinary team of researchers in machine learning, computer systems, cognitive psychology, and education from Rice University and Duke University in developing a data-centric personalized learning system called OpenStax Tutor (openstaxtutor.org). Its three central elements are:

- **Cognitive science.** We leverage three cognitive science principles—retrieval practice, spacing, and feedback—that are robust and highly replicable; generalize themselves across different types of learners, materials, and contexts; and increase long-term retention and transfer of learning. To maximize learning efficacy, the learning plan carefully sequences content and practice opportunities to allow retrieval practice and spacing while providing detailed, timely, and appropriate feedback.
- **Open community.** We expand the universe of learning content, problems, solutions, and feedback available to the learner by bringing together materials and metadata generated by an open community of contributors, including conventional authors, educators, and even learners. In particular, we leverage Connexions and QuadBase (quadbase.org), an open-source repository of homework and test questions founded at Rice University.

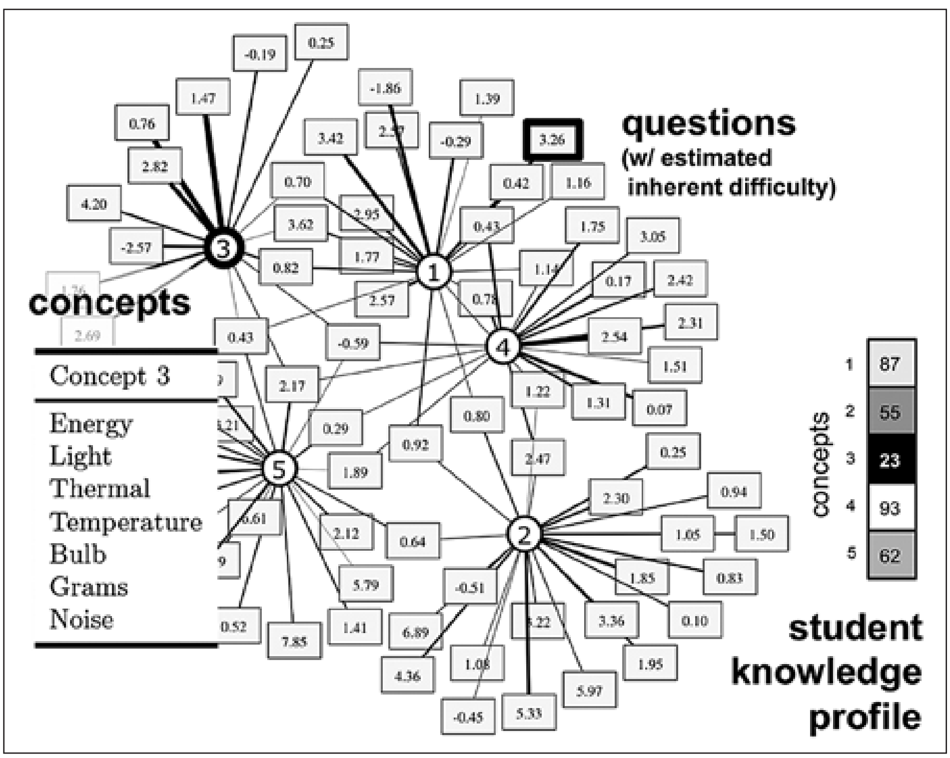

FIGURE 2 The result of applying a sparse factor analysis (SPARFA; Lan et al. 2012) learning/content analytics algorithm to data from a grade 8 science course in STEMscopes, an online science curriculum program. The data input to SPARFA consisted solely of whether a student answered a given potential homework or exam question correctly or incorrectly. From these limited and quantized data, SPARFA automatically estimates (a) a collection (in this case five) of abstract "concepts" that underlie the course ("Concept 3" is illustrated here); (b) a graph that links each question (rectangular box) to one or more of the concepts (circles), with thicker links indicating a stronger association with the concept; (c) the intrinsic difficulty of each question, indicated by the number in each box; (d) descriptive word tags drawn from the text of the questions, their solutions, and instructor-provided metadata that make each concept interpretable (as shown for Concept 3); and (e) each student's knowledge profile, which indicates both estimated knowledge of each concept and concepts ripe for remediation or enrichment. Reprinted with permission from Lan et al. (2012).

- **Machine learning.** We increase the flexibility, generalizability, and scalability of OpenStax Tutor by eschewing hand-coded rule-based systems for providing feedback in favor of data-driven machine learning algorithms that adapt and optimize feedback and learning plans by analyzing the content, problems, and solutions plus data from a large number of learner interactions. For example, Figure 2 illustrates a concept graph that was automatically generated by a sparse factor analysis (SPARFA) learning/content analytics algorithm using only the course "grade book" matrix indicating which students answered which questions (in)correctly (Lan et al. 2012).

In beta testing, Rice University electrical and computer engineering students who used OpenStax Tutor during the 2011–12 academic year improved their learning outcomes by one-half to one letter grade compared to those who relied on the standard practice of weekly homework without retrieval practice, spacing, and timely feedback. Beta testing is continuing with engineering students at Rice, Georgia Tech, the University of Texas at El Paso, and the Rose-Hulman Institute of Technology (Terre Haute, Indiana).

Personalized learning systems like OpenStax Tutor can both enhance the learning experience for students and provide college instructors and K–12 teachers with immediate data to better inform their instruction and forge a more direct connection with their students. They enable teachers to immediately understand not only how their students are performing on the core course concepts but also what they are doing that influences their students' success (and failures) in their learning. Significantly more efficient and effective learning should result.

Credit and Open Certification

OER and MOOCs enable flexible new ways to learn, but how do students (of any age) get credit for what they've learned? Today, in order to get credit, one typically enrolls in a rigid, often multiyear program that measures learning achievement in terms of "seat time." Such rigidity is no longer practical in the modern knowledge economy, as more and more careers require constant training on new knowledge and skills. As John Seely Brown (2005, p. 4.3) put it, "As [workers] move from career to career, much of what they will need to learn won't be what they learned in school a decade earlier. They will have to be able to pick up new skills outside of today's traditional educational institution."

Clearly, students and lifelong learners need a more flexible system for certifying their skills acquired both in and out of school. Again, communication and information technologies offer a solution.

Recently developed "stacked credentials" record and track learning achievements in subjects such as web design, welding, and calculus. In particular, Mozilla's Open Badges project (mozilla.org/badges) has developed tools to make it easy to earn, issue, and display "badges" (a simple kind of credential) on the web. Badges allow people to provide a more complete picture of their skills and competencies to potential employers, mentors, peers, and collaborators. They acknowledge the fact that learning happens everywhere (not just in school) and document much more than a report card about people's acquired skills and competencies. The beauty of badges is that, like OER, they are modular and thus enable learners to build a career ladder over time, transforming the learner from a passive consumer in a constrained system to an active participant in a lifelong process.

MOOC and badge-based certification are nascent but gaining momentum, as illustrated in the following examples:

- The major MOOC providers all offer a certificate of accomplishment for students who successfully complete their courses online.
- The American Council on Education is reviewing MOOCs offered by several elite universities and may recommend that other colleges grant credit for them (Young 2012).
- Industry associations, such as the Manufacturing Institute, are developing badges that recognize skills highly sought after by manufacturers.
- Peer-to-Peer University (p2pu.org), a grassroots OE project, is offering badges for the completion of online courses.

The Open Road Ahead

The world is increasingly connected, yet educational systems cling to the disconnected past. The OE movement provides new mechanisms to democratize education by interconnecting ideas, learners, and instructors in new kinds of constructs that replace traditional textbooks, courses, and certifications. OE has the potential to realize the dream of providing not only universal access to all the world's knowledge but also the tools required to acquire it. The result will be a revolutionary advance in the world's standard of education at all levels.

But OE is also a disruptive force in the academic world (Christensen and Horn 2011). OER promises to disintermediate the scholarly publishing industry, rendering some current business models unviable and inventing new viable ones. Furthermore, MOOCs, badges, and personalized learning systems have the potential to disaggregate schools and colleges, enabling new efficiencies but also devaluing certain aspects.

Thus, however exciting, the OE movement raises many questions, most of them revolving around ways to maximize the impact of OE while mitigating undesired, unintended consequences. Research and experience are needed to address the following questions:

- What measures may be necessary to prevent OE from "regressing to the mean" and providing only an average education to an average student?
- What is the balance between the (inexpensive) massive online aspect of OE and the (expensive) face-to-face contact that defines current education systems?
- Will the future of education be dominated by a few massive "university networks" with "talking head" instructors?
- What is the utility of a final exam or high-stakes test when machine learning analytics can accurately predict a student's score from the regular coursework?
- How much does teaching improve with the use of learning analytics to track both student and instructor performance?
- Can the use of analytics transform the educational system from one where time is held constant and the amount of learning is variable to a system where the amount of learning is held constant and time is the variable?
- Are there risks or tradeoffs if companies looking to hire prefer a solid collection of industry-approved badges over a college degree?
- How does OE impact academic freedom?
- What measures may be necessary to safeguard a student's lifelong electronic learning record?
- How can OE enterprises be financially sustained over the long term while remaining as accessible as possible?

Clearly the education world is in for a turbulent, yet fruitful, next decade.

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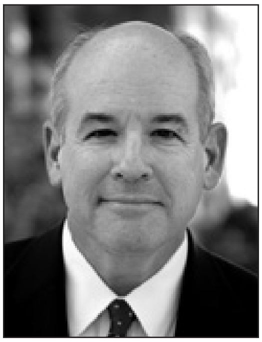
Massachusetts has created a comprehensive, collaborative model for supporting STEM education in the practical context of career readiness and industry needs.

State-Level Measures to Close the STEM Skills Gap



Dennis D. Berkey

Joanne Goldstein

Dennis D. Berkey and Joanne Goldstein

The Commonwealth of Massachusetts enjoys a citizenry highly educated in the sciences, technology, engineering, and mathematics (STEM) as well as thriving high-tech and life sciences industries. Yet there is a shortage of workers appropriately trained and educated for what are often referred to as middle-skills jobs in these industries. Such jobs—lab technician, computer specialist, advanced manufacturing technician, radiation therapist, airplane mechanic, and EMT professional, among others—account for 45 percent of US employment (44 percent in Massachusetts) (Holzer and Lerman 2009).

To address this shortage, business and political leaders across the country have called for an increase in the number of students receiving baccalaureate and advanced degrees in STEM fields. But employers point to a shortfall of employees with *basic* competencies appropriate to functioning in the technology-intense environments of today's workplaces. For instance, a 2005 report by the National Association of Manufacturers found that, although 35 percent of manufacturers anticipated a shortage of scientists and engineers in the coming decade, more than twice as many anticipated a dearth of skilled production workers (NAM 2005). That situation has

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not changed. In January 2012 Massachusetts Governor Deval Patrick reported that 240,000 people were seeking employment while 120,000 jobs sat unfilled.[1] Many of these jobs do not require advanced degrees but rather the skills and knowledge of a two-year associate's degree or specialized training available in technical/vocational high schools.

The responsibility to prepare young citizens for a productive and fulfilling life means providing them with a quality education and the know-how to use that education for personal and professional achievement. This is especially true during times of economic stress, when unemployment is high and opportunities are in short supply. It's even more imperative when there is a disconnect between growth industries and the skilled workers needed to advance that industry.

Governor Patrick and his administration are addressing these challenges through their commitment to education at all levels, and they are doing so in a highly collaborative way. Massachusetts has established a number of public-private partnerships among industry, academia, and government. The governor also called on his secretaries of Economic Development, Labor and Workforce Development, and Education to coordinate their efforts to prepare the state's youth and adults for middle-skills jobs that are in demand. And he created the position of Director of Education and Workforce Development (who reports to all three secretaries) to engage high schools and community colleges in building career pathways that correspond to industry demand, beginning with advanced manufacturing, life sciences, health care, and information technology. As described below, these efforts are already producing impressive outcomes that offer students more educational choices, better career readiness, and greater access to employment.

Strategic Partnerships

Massachusetts has made significant investments in leadership for STEM education across the K–12 spectrum. For example, the governor's STEM Advisory Council, established in 2009, is a dynamic forum for meaningful collaboration among STEM advocates from business, government, and education. It is the state's principal

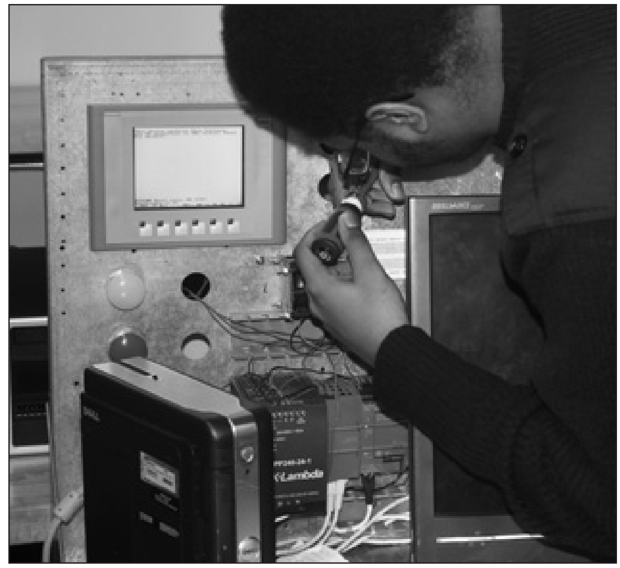

FIGURE 1 A Worcester Technical High School student prepares his project for an upcoming class.

entity for promoting study and achievement in STEM subjects, reaching out to students and their parents as well as the general public.

Early on, the STEM Council, in an effort called @Scale, identified and promoted programs that were working well and could be scaled up for broader impact. One such program, the Mass Math + Science Initiative (MMSI; part of the National Math and Science Initiative), has increased enrollment and outcomes in advanced placement (AP) classes in STEM and in English language courses, especially among minority and low-income students. MMSI combines rigorous study with multiple levels of academic support, including extended-day and weekend tutoring, and professional development for teachers.

The attention paid to these areas has influenced Massachusetts schools, particularly the commonwealth's vocational and technical high schools. An example of such is the recent high achievements at Worcester Technical High School (Figure 1). Under the visionary leadership of principal Sheila Harrity, and with strong support from the business community, Worcester Tech has gone from the lowest- to the highest-performing school in the Worcester Public School System on the Massachusetts Comprehensive Assessment System in just six years. In 2012, 88 percent of the students scored in either the "advanced" or "proficient" categories in English/language arts and 78 percent in mathematics, compared to 27 and 35 percent, respectively, just six years earlier. Moreover, Worcester Tech is enrolling

[1] Massachusetts 2012 State of the Commonwealth Address, January 23, 2012. Available online at www.mass.gov/governor/pressoffice/speeches/23012012state-of-the-commonwealth-address.html.

increasing numbers of students in honors or AP courses, and more than 70 percent of its graduates go on to four-year colleges or universities.[2]

Worcester Tech has also engaged community partners to develop new career-oriented programs. One example is a partnership with Tufts University's Cummings School of Veterinary Medicine, which runs the Tufts at Tech Community Veterinary Clinic, a student-run clinic at the high school. This innovative learning facility, using students from both schools, gives high school students an opportunity to learn from veterinarians, and offers citizens in the greater Worcester area affordable veterinary care. The Tufts program is just one of a range of offerings at Worcester Tech that combine career readiness with strong academic skills.

There is significant overlap between the courses and experiences that lead to both college and career readiness.

Education of Students and Parents

Another goal of the Massachusetts K–12 initiatives has been to educate both students and their parents about the knowledge and skills needed to succeed in the 21st century. To that end, education and business leaders from across the commonwealth came together in a special task force, Integrating College and Career Readiness (ICCR), which was established in 2011 by the Massachusetts Board of Elementary and Secondary Education and completed its work in July 2012.[3]

The mission of the ICCR task force was to propose ways to increase student and parent awareness of the advantages of early thinking about career plans, to determine whether or not they involve college-level preparation, and to ensure the acquisition of necessary knowledge and abilities. The task force noted that although parents are prime influencers in a student's education, they are often unaware of the educational requirements associated with specific career opportunities. It is therefore important to educate and inform parents as much as students.

Among the pertinent findings of the task force was that there is significant overlap between the courses and experiences that lead to success in both college and careers, and that students who pursue studies in math and science have an advantage in both. Moreover, many growth industries require technical know-how and at least a basic familiarity with mathematical and scientific thinking, so continuing engagement in these areas strengthens a student's preparedness. Thus the task force emphasized the value of (1) continued study in STEM subjects throughout high school and (2) internships, engagement with mentors from the business community, and other practical means of enabling students to understand the nature and requirements of the world of work. This finding raises worthwhile concerns about persistent distinctions made in some schools between "college prep" and "general" tracks of study.

To further enhance student preparedness, Massachusetts adopted a high school program known as MassCore that requires four years of English, four years of mathematics, and three years of a lab-based science. MassCore is designed to ensure that all students graduate with the basic knowledge and skills they will need to succeed in college, career, and citizenship.

Community Colleges and Internships

Massachusetts recognizes that community colleges are vital to closing the skills gap, especially through coordination of their curricula and learning outcomes with the needs of growth industries.

To that end, the Massachusetts Life Science Education Consortium (MLSEC) designated subcommittees, composed of leaders from business, higher education, and the MLSEC staff, to study the life sciences curricula at community colleges along with the skills requirements for middle-skills jobs in that industry. The study showed that 8 of the commonwealth's 15 community colleges meet or exceed the defined criteria for an effective program, while also identifying opportunities to enhance the remaining programs. The 8 selected programs, designated "gold" or "silver" depending on whether they include an internship opportunity, earn a three-year endorsement from the MLSEC, which in turn posts information

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[2] These results are available online at www.golocalworcester.com/news/the-secret-formula-at-worcester-technical-high-school/.

[3] Information about the task force's mission, work, and members is available online at www.doe.mass.edu/news/news.aspx?id=6919.

online so that students can identify the community college programs best suited to their interests.[4]

FIGURE 2 Instructor Ed Davis (left) of Bristol-Myers Squibb works with a student at the Biomanufacturing Education and Training Center (BETC) at Worcester Polytechnic Institute.

The Massachusetts Life Sciences Center (MLSC) is a quasi-public agency created to administer Governor Patrick's 2008 commitment to $1 billion in funding for the life sciences industry over the next 10 years. The MLSC facilitates collaboration between industry leaders and two- and four-year colleges to promote the alignment of curricula with life sciences industry sectors experiencing worker shortages. The MLSC also works to ensure that students receive not only the education and training needed to succeed in the life sciences but also professional mentoring and guidance on how best to enter and navigate this rapidly growing field.

One of the MLSC's most successful programs is its Internship Challenge, which offers Massachusetts college students opportunities for real-world experience in the life sciences industry.[5] The Challenge strengthens the talent pipeline for the industry by offering companies—large and small, startup and established—funding for paid internships to be awarded to the strongest applicants. These internships expand the pool of prospective employees, enabling more students to explore career opportunities while learning firsthand how their knowledge gets applied. Since the program launched in 2009, MLSC has placed over 900 interns at nearly 300 companies throughout Massachusetts.

Workforce Training and Development

Massachusetts recognizes the need for labor force development for its adult population and has invested in postsecondary education training programs and facilities. The commonwealth helps adults remap their skill sets through a system of services and tools overseen by the Executive Office of Labor and Workforce Development. For example, the online One-Stop Career Center helps thousands of job seekers access education and training opportunities in STEM and other fields.

In addition, the state's Workforce Training Fund ensures that resources are available to employers to train their incumbent workforce. Since its inception in 1998, the fund has awarded grants totaling nearly $214 million to train over 301,000 workers at over 4,000 companies in the manufacturing, professional, technical, services, and other industries critical to the commonwealth's economic growth.

Massachusetts colleges also strengthen the STEM workforce in a variety of ways. One example is the state's partnership with Worcester Polytechnic Institute (WPI). Both partners have invested in a new, state-of-the-art Biomanufacturing Education and Training Center (BETC; Figure 2), located on the WPI campus. The MLSC gave $2.9 million to fund the facility's build-out costs as well as a $250,000 equipment grant. Similarly, the University of Massachusetts Dartmouth broke ground last year on a biomanufacturing facility that will offer real-world training opportunities for students.

These are just a few of the wide range of programs developed through collaborative efforts and funded by the Commonwealth of Massachusetts and its leading industries.

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[4] The community colleges and descriptions of their biotech programs are posted on the MLSEC website, www.massbio.org/public_policy/state_issues/workforce_development/massachusetts_life_sciences_education_consortium/biotechnology_programs.

[5] Information about the MLSC Internship Challenge is available online at www.masslifesciences.com/grants/challenge.html.

The Way Forward

Massachusetts has enjoyed a long and distinguished history of innovation. From the birth of the American Industrial Revolution to life-changing medical breakthroughs to the rise of the computer industry to the parsing of the human genome, Massachusetts has been home to some of the nation's most dynamic innovations, in large part because of its exceptional system of higher education, both public and private.

Today, however, it is no longer viable to view postsecondary education solely through the prism of undergraduate and graduate degree programs. With a large portion of students falling outside that category, and with the increasing need for development initiatives that target the middle-skills workforce, Massachusetts has created a comprehensive and collaborative model for supporting STEM education in the practical context of career readiness and industry needs. This model has flourished thanks to a series of policy initiatives invoking public-private partnerships and investments in STEM education, from K–12 through community colleges, four-year universities, and workforce development programs.

Massachusetts colleges and universities have long championed lifelong learning, which has never been more relevant than today. The pace of innovation and discovery makes continuous learning essential for the modern workforce. And advances in technology are changing not only the way people work but the way they learn. From online colleges to certificate programs at community colleges to distance learning and massive open online courses, students and professionals have more choices and opportunities to gain the education they need to position themselves for rewarding careers. Ensuring that these new forms of learning are widely known and accessible is just one way that the state has leveraged the power of its STEM education system.

In our positions at the Worcester Polytechnic Institute and the state's Office of Education and Workforce Development, we are proud to help Massachusetts benefit from the expertise and interest of academia, industry, and government, collaborating to identify and implement strategies that strengthen workforce development while providing young people with better-informed educational choices, stronger outcomes, and greater access to careers in rapidly growing sectors of the economy. We hope that the report of these achievements will be useful to others with similar aspirations.

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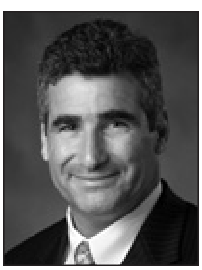
The Grand Challenge Scholars program gives students a better understanding of how their undergraduate work prepares them to face their careers and important societal challenges.

The NAE Grand Challenge Scholars Program

Tom Katsouleas, Richard Miller, and Yannis Yortsos


Tom Katsouleas


Richard Miller


Yannis Yortsos

In 2007 the National Academy of Engineering, with support from the National Science Foundation, convened a panel of leading thinkers from academia, policy, and business with the charge of identifying a small number of grand challenges for engineering in the 21st century. Their extraordinary list of 14 representative challenges (Box 1) spans the need for sustainability, health, security, and joy of living.

The challenges are remarkable because they both convey in very human terms what engineering is and will be about, and clearly show that these concerns are global in nature (e.g., manage the nitrogen cycle), necessarily connected to behavior and policy as well as business (e.g., make solar energy economical), and tap into social consciousness (e.g., provide clean water).

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BOX 1
The 14 NAE Grand Challenges for Engineering in the 21st Century

- Make solar energy economical
- Provide energy from fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics
- Engineer better medicines
- Reverse-engineer the brain
- Prevent nuclear terror
- Secure cyberspace
- Enhance virtual reality
- Advance personalized learning
- Engineer the tools of scientific discovery

Available online at www.engineeringchallenges.org.

We view the NAE Grand Challenges as a call to action—for the profession and, more specifically to this article, for engineering education.

What's Different about the Grand Challenge Scholars Program

The NAE Grand Challenge Scholars program (http://grandchallengescholars.org) was announced at the first NAE Grand Challenges Summit in Durham, North Carolina, in 2009.[1] It is designed to prepare engineering undergraduates with the skills and mindset to tackle the challenges over the course of their careers. It is now under way at 13 leading universities (Box 2).

In addition to the engineering requirements for their degree, students who complete the program create a portfolio with the following five components:

1. Global education experience
2. Service learning
3. Entrepreneurship
4. Broad general education, including behavior, economics, and policy
5. Hands-on research or project related to one of the Grand Challenges

[1] Information about the Grand Challenges Summit Series is available online at http://summit-grand-challenges.pratt.duke.edu.

BOX 2
Active Grand Challenge Scholars Programs

- Duke University, Pratt School of Engineering
- The Franklin W. Olin College of Engineering
- University of Southern California, Viterbi School of Engineering
- Arizona State University, Ira A. Fulton School of Engineering
- Louisiana Tech University, College of Engineering and Science
- North Carolina State University, College of Engineering
- University of Iowa, College of Engineering
- Lafayette College, Division of Engineering
- University of Tennessee, College of Engineering
- Bucknell University, Bucknell College of Engineering
- Western New England College, School of Engineering
- St. Louis University, Parks College of Engineering, Aviation & Technology
- University of Texas at Austin, Cockrell School of Engineering

Upon completion participating students receive the designation of NAE Grand Challenge Scholar on the transcript from their home institution with the imprimatur of the NAE.

It is worth noting that the Grand Challenge Scholars program leverages and complements existing research and programs in modern engineering education pedagogy. Indeed, most top engineering schools already offer some or all of the five components listed in some form or another. What, then, is the value of bringing them together in this program? That there would be an answer was not certain to us when the initiative was conceived but student response so far indicates that there are several answers to the question "Aren't engineering schools already doing this?" First, the Grand Challenge Scholars program compels students to stretch to do all five rather than a few of the components. Second, it is one of the few programs that recognizes in the transcript the value (demonstrated through research and experience) of out-of-classroom learning. Third, and more significantly, the overwhelming feedback is that the process of creating their portfolio, as much as the experiences themselves, helps students appreciate the value of those experiences. They gain a better understanding of how everything they have been doing in their undergraduate work comes together to prepare them to face their careers and important societal challenges.

Evidence of Impact

In 2008, the NAE report *Changing the Conversation: Messages for Improving Public Understanding of Engineering* urged a reframing of what engineering involves to connect with a new generation of students, not to mention the public at large, who are more motivated than ever to change the world and to help people. The Grand Challenges and Scholars program respond directly to that call in a most powerful way.

In 2009, an independent survey conducted for the organizers of the first NAE Grand Challenges Summit measured the responses of several demographics to questions about the importance of engineering relative to medicine, business, and law before and after the respondents heard a brief description of the NAE Grand Challenges. The results were dramatic. After hearing the description, the respondents who rated engineering as *more important/more interesting* than the other fields increased from 40 percent to 54 percent, and the number who rated it *much more important/interesting* rose from 18 percent to 27 percent. Moreover, the increases were largest among women and underrepresented groups.[2] As a further data point, at one of our institutions (USC), since the recruitment materials for high school seniors was modified to include the Grand Challenges the enrollment of women in the entering class has risen to 38 percent. The Grand Challenge Scholars program then continues to foster that interest once the students are on the college campus.

All of the Grand Challenge Scholars programs have in common the five components above, but differ in their implementation. At Olin College, the development of a comprehensive student portfolio integrating the five Grand Challenge elements (and often other elements involving projects of various kinds) is the primary method of implementation of the Scholars program. Other engineering schools offer freshman seminar or overview courses that incorporate the Grand Challenges.

In most cases, admission to the program is highly selective and takes place later in the undergraduate career. At USC, for example, portfolios of candidates for the distinction Grand Challenge Scholar are submitted for selection and recognition at graduation. At Duke, students attend information sessions in their sophomore year and apply in their junior year; financial support (about $5,000 per student) is provided primarily for the hands-on component, thanks to an endowment from generous donors.[3]

Incorporating the Grand Challenges in K–12 Education

At a 2010 meeting in St. Petersburg, Florida, engineering deans were polled for their views as to whether and why Grand Challenges for Engineering should be introduced at the K–12 level. The majority (65 percent) responded that teaching about the challenges in K–12 was important for educating and motivating the public to be a part of their solution. About a third (31 percent) responded that the most important reason to teach the Grand Challenges was to increase the interest in and pipeline for engineering. (Only 4 percent responded that the Grand Challenges were not important to or were too hard for K–12 students.)

K–12 teaching about the Grand Challenges can both motivate the public to be a part of their solution and increase the pipeline for engineering.

Later that year a program aimed at bringing the Grand Challenges to K–12 education (www.grandchallengek12.org) was announced, at the Regional Grand Challenge Summit in Raleigh, North Carolina, cohosted by Duke and North Carolina State

[2] The survey results are available online at http://summit-grand-challenges.pratt.duke.edu/national-survey.

[3] These donors are Susie Simon and the Niarchos Foundation. It is worth noting that the Niarchos Foundation supports social causes and the arts primarily, and originally did not see a connection between its mission and an engineering school. After learning about the NAE Grand Challenges, foundation representatives were enthusiastic that this kind of program is exactly in line with the foundation's mission.

University (NCSU) under the leadership of NCSU Engineering Dean Louis Martin-Vega. Dubbed the NAE Grand Challenges K–12 Partners Program, this national effort attempts to address the two priorities reflected in the deans' survey. It translates the five components of the Grand Challenge Scholars program to a pedagogy appropriate for K–12 students, creating a resource for teachers with ideas for lesson plans that tie to Common Core and state standards. It also connects undergraduate Grand Challenge Scholars to area schools where they can bring the excitement of the challenges and their own experiences to school children.

Another novel application of the Grand Challenges in K–12 pedagogy is being employed with success at a new magnet high school in the Wake County Public School System on the NCSU campus. The Grand Challenges are infused throughout the curriculum. For example, the challenge "provide clean water" involves an integrated engineering and social studies project comparing water quality at two watersheds in North Carolina. Students perform hands-on water filtration studies and examine the geological and political factors that result in very different water quality in each case.

Expanding and Moving Forward

There have been efforts to broaden the use of the Grand Challenges approach to disciplines beyond engineering. For example, discussions are under way to explore the possibility of creating a Grand Challenge Scholars program for business and liberal arts majors at Babson College and Wellesley College.

Internationally, the NAE recently partnered with the Royal Academy of Engineering (RAE) and the Chinese Academy of Engineering (CAE) to sponsor a follow-on to the US summits and identify the need and opportunities for global cooperation to address the Grand Challenges. That meeting took place in London, March 12–13, 2013. To support research and the role of graduate students, eight universities active in Grand Challenges education announced a PhD scholarship program, called the Charles M. Vest NAE Grand Challenges for Engineering Scholarships (the Vest Scholarships for short; http://vestscholars.org). The Scholarships are intended to be something like a reverse Rhodes Scholarship; they provide resources for a PhD student from abroad to study for a year at one of the eight schools, working with faculty on a Grand Challenge topic and then returning to their home institution to complete their degree. The hope is that the scholarships will (1) enrich the participants through their overseas experience, (2) enhance global collaborations that will lead to Grand Challenge solutions, and (3) form a network of scholars, with a common determination to tackle the world's most difficult and important problems, on which the students will draw throughout their careers.

In summary, the NAE Grand Challenges for Engineering in the 21st century are a powerful framing of what the field of engineering is and will become, one that excites and engages young people and the public alike. Moreover, they are an opportunity to "change the conversation" about engineering and to enhance engineering education to give students at all levels the skills and mindset to solve them.

Reference

NAE [National Academy of Engineering]. 2008. Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington: National Academies Press.

NAE News and Notes

Charles M. Vest NAE President 2007–2013

Charles M. Vest was elected in 2007 to a six-year term as president of the National Academy of Engineering and will complete his tenure on June 30, 2013. He is also president emeritus of the Massachusetts Institute of Technology.

Dr. Vest earned a BS in mechanical engineering from West Virginia University in 1963 and MSE and PhD degrees in mechanical engineering from the University of Michigan in 1964 and 1967 respectively. In 1968 he joined the faculty of the University of Michigan as an assistant professor; he taught in the areas of heat transfer, thermodynamics, and fluid mechanics, and conducted research in heat transfer and engineering applications of laser optics and holography. He and his graduate students developed techniques for making quantitative measurements of various properties and motions from holographic interferograms, especially the measurement of three-dimensional temperature and density fields using computer tomography. He became an associate professor in 1972 and a full professor in 1977. In 1981 he turned much of his attention to academic administration and served as the university's associate dean of engineering (1981–1986) and dean of engineering (1986–1989) before becoming provost and vice president for academic affairs.

In 1990 Dr. Vest was elected president of the Massachusetts Institute of Technology (MIT) and served in that position until December 2004, when he became professor and president emeritus. As president of MIT, he was active in science, technology, and innovation policy; building partnerships among academia, government, and industry; and championing the importance of open, global scientific communication, travel, and the sharing of intellectual resources. During his tenure, MIT launched its OpenCourseWare (OCW) initiative; cofounded the Alliance for Global Sustainability; enhanced the racial, gender, and cultural diversity of its students and faculty; established major new institutes in neuroscience and genomic medicine; and redeveloped much of its campus.

Charles M. Vest

Dr. Vest began his term as president of the National Academy of Engineering in 2007. Under his leadership, the NAE promoted the Grand Challenges for Engineering, a set of 14 critical challenges for engineers in the 21st century, which, if achieved, will improve the quality of life for humankind. This effort spawned a number of Grand Challenges Summits at universities around the country and has contributed to better public understanding of the value and importance of engineering advances to the well-being of the nation and the world.

Dr. Vest presided over the international expansion of the NAE's Frontiers of Engineering (FOE) program to include partnerships with China and the European Union. In 2009, he launched the annual NAE Frontiers of Engineering Education symposium series, aimed at identifying and propagating innovative approaches to engineering teaching and learning. He also initiated a major new NAE effort to understand and address changes in global manufacturing-design-innovation value chains and their implications for US employment, education, and competitiveness. And under his leadership the NAE in 2011 developed a novel partnership with the US Institute of Peace to consider how the application of technology and of knowledge and methods from engineering and science can serve the goals of conflict prevention, peacemaking, and peacekeeping.

In addition to strengthening and augmenting the strategic programs of the NAE, Dr. Vest exercised his visibility as NAE president to great effect, playing a prominent role both nationally and internationally in illuminating forces reshaping the landscape of engineering research, practice, and education, and in defining the attributes future engineers will require to compete and lead in the emerging global economy.

Dr. Vest was a director of DuPont for 14 years and of IBM for 13 years, and vice chair of the US Council on Competitiveness for 8 years. He also served on various federal committees and commissions, including the President's Committee of Advisors on Science and Technology (PCAST) during the Clinton and Bush administrations, the Commission on the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction, the Secretary of Education's Commission on the Future of Higher Education, the Secretary of State's Advisory Committee on Transformational Diplomacy, and the Rice-Chertoff Secure Borders and Open Doors Advisory Committee. He serves on the boards of several nonprofit organizations and foundations devoted to education, science, and technology. He has authored a book on holographic interferometry and two books on higher education. He has received honorary doctoral degrees from 17 universities, was awarded the 2006 National Medal of Technology by President Bush, and received the 2011 Vannevar Bush Award from the National Science Board.

We greatly appreciate Dr. Vest's thoughtful guidance and significant contributions in bolstering the NAE's national leadership during his term, and wish him all the best in his future pursuits.

NAE Newsmakers

David D. Awschalom, professor of physics and of electrical and computer engineering at the University of California, Santa Barbara, has been **elected to the European Academy of Sciences**. The academy, which elects relatively few non-European scientists, bases its selections on new research fields that have substantial scientific impact. Professor Awschalom is known for his pioneering research in spintronics and quantum information science. Spintronics specialists manipulate the spin of electrons and nuclei to devise new methods for advanced computing, medical imaging, subatomic memories, encryption, and other technologies. His patents include one for quantum computing, an experimental computer technology that would greatly outperform modern digital computers.

The Marconi Society has announced that **Martin Cooper**, chairman of Dyna LLC, is the recipient of the **2013 Marconi Prize**, considered the highest honor in the field of communications and information science. Mr. Cooper, a wireless visionary and serial entrepreneur, is credited with developing the concept of the handheld mobile phone. He led the team that put Motorola at the forefront of a burgeoning new industry and he helped reshape and point the global telecommunications industry in a new direction. The $100,000 Marconi Prize, to be presented at a ceremony this fall in Bologna, Italy, is given each year to one or more scientists and engineers who, like radio inventor Guglielmo Marconi, achieve advances in communications and information technology for the social, economic, and cultural development of all humanity.

The Association for Computing Machinery (ACM) and the Infosys Foundation announced that Google Fellows **Jeffrey Dean** and Sanjay Ghemawat are the recipients of the **2012 ACM–Infosys Foundation Award in the Computing Sciences**, presented at the annual ACM awards banquet on June 15 in San Francisco. The award recognizes personal contributions by young scientists and system developers to a contemporary innovation that exemplifies the greatest recent achievements in the computing field. Drs. Dean and Ghemawat led the conception, design, and implementation of much of Google's revolutionary software infrastructure, which underlies the company's web search and indexing as well as numerous applications across the industry. The technology has been emulated by virtually every major Internet company in the world. The scalable infrastructure they created was also pivotal to the burgeoning field of cloud computing, which delivers resources over the Internet. An endowment from the Infosys Foundation provides financial support for the $175,000 annual award.

ACM selected **Shafi Goldwasser**, professor of computer science and artificial intelligence at the Massachusetts Institute of Technology (MIT) and the Weizmann Institute of Science, and professor **Silvio**

Micali, also at MIT, as the recipients of the **2012 ACM A.M. Turing Award**. Working together, they pioneered the field of provable security, which laid the mathematical foundations that made modern cryptography possible. By formalizing the concept that cryptographic security had to be computational rather than absolute, they transformed cryptography from an art to a science. Their work addresses the protection of data from being viewed or modified, providing a secure means of communications and transactions over the Internet. The ACM Turing Award, widely considered the "Nobel Prize in Computing," carries a $250,000 prize, with financial support provided by Intel Corporation and Google Inc. ACM presented the award at its annual awards banquet on June 15 in San Francisco, California.

Maurice Herlihy, professor of computer science at Brown University, has been named the 2013 recipient of the Institute of Electrical and Electronics Engineers (IEEE) Computer Society's prestigious **W. Wallace McDowell Award** for his contributions to multiprocessor computation. Dr. Herlihy, whose research focuses on practical and theoretical aspects of concurrent and distributed computing, was recognized for his "fundamental contributions to the theory and practice of multiprocessor computation." His early work on wait-free synchronization showed that different synchronization operations have different computational power, but that any operation that can solve consensus is universal. The McDowell Award is given to individuals for outstanding recent theoretical, design, educational, practical, or other innovative contributions in the field of computing.

Chenming Hu, TSMC Distinguished Professor of the Graduate School at the University of California, Berkeley, has been selected by the Electronic Design Automation Consortium and the IEEE Council of EDA to receive the **2013 Phil Kaufman Award for Distinguished Contributions to Electronic Design Automation** (EDA). The award was presented June 2 at the opening ceremony of the largest EDA event, the Design Automation Conference, in Austin, Texas. Dr. Hu was recognized for his contributions in device physics, device modeling, and device reliability through BSIM and BERT models that have transformed the semiconductor manufacturing and electronic design automation industries. His team invented the revolutionary 3D FinFET transistor structure that simultaneously achieves size and power reduction to enable continued scaling of the microelectronic chips. The Phil Kaufman Award honors individuals who have had demonstrable impact on the field of EDA through technology innovations, education/mentoring, business or industry leadership. It was established as a tribute to Phil Kaufman, the late industry pioneer who turned innovative technologies into commercial businesses that have benefited electronic designers.

The American Association for the Advancement of Science (AAAS) has chosen **Anita Jones**, University Professor Emerita, School of Engineering and Applied Science, University of Virginia, to receive its highest honor, the **2012 Philip Hauge Abelson Award**. A specialist in computer security systems, Dr. Jones was honored for her scientific and technical achievements in computer science; her contributions as a mentor, inspiration, and role model for other scientists and engineers; and her lifetime of public service to government, professional institutions, academia, and industry. She received the award on February 15 at a ceremony and reception during the association's 179th annual meeting in Boston.

Jay Keasling, Hubbard Howe Jr. Distinguished Professor of Biochemical Engineering at the University of California, Berkeley, is the winner of the **2013 Promega Biotechnology Research Award** presented by the American Society of Microbiology. The award honors significant contributions to the application of biotechnology through fundamental microbiological research and development. Professor Keasling is a pioneer and international leader in engineering microorganisms to produce active pharmaceutical ingredients, commodity chemicals, specialty polymers, and biofuels. His research focuses on engineering microorganisms for environmentally friendly synthesis of small molecules or degradation of environmental contaminants.

Sangtae Kim, executive director of the Morgridge Institute for Research, has received the **2013 Ho-Am Engineering Prize** from South Korea, the highest engineering research award issued by that nation. The prize recognizes Dr. Kim's influential scholarship in the field of chemical engineering for the past three decades. The award includes a prize of about $265,000, a gold medal, and a laureate diploma.

Cato T. Laurencin, University Professor; Albert and Wilda Van Dusen Distinguished Professor of Orthopaedic Surgery; professor of chemical, materials, and biomolecular engineering; CEO, Connecticut

Institute for Clinical and Translational Science; and Director, Institute for Regenerative Engineering, University of Connecticut, received the 2012 AAAS **Mentor Award** "for his transformative impact and scientific contributions toward mentoring students in the field of biomedical engineering." The award honors AAAS members who have mentored significant numbers of underrepresented students (women, minorities, and persons with disabilities) toward a PhD degree in the sciences, as well as scholarship, activism, and community building on behalf of underrepresented groups in science, technology, engineering, and mathematics fields. It was presented during a February 15 ceremony at the 2013 AAAS Annual Meeting in Boston.

Roderic Pettigrew, director of the National Institute of Biomedical Imaging and Bioengineering (NIBIB), received the **2013 Pierre Galletti Award** from the American Institute for Medical and Biological Engineering (AIMBE) at the 2013 AIMBE Annual Event in Washington, DC. It is the highest honor that AIMBE, a nonprofit organization that provides leadership and advocacy in medical and biological engineering for the benefit of society, bestows on an individual.

Frank D. Robinson, founder and retired president of Robinson Helicopter Company, has been selected to receive the **2013 Daniel Guggenheim Medal** for his "conception, design, and manufacture of a family of quiet, affordable, reliable, and versatile helicopters." Established in 1929 to honor notable achievements in aeronautics, the Daniel Guggenheim Medal is awarded jointly by the American Institute of Aeronautics and Astronautics (AIAA), the American Society of Mechanical Engineering (ASME), the American Helicopter Society (AHS) International, and the Society of Automotive Engineers (SAE) International.

The Carnegie Science Center has announced that the prestigious **Chairman's Award** of the 2013 Carnegie Science Awards will go to Ralph J. Cicerone, president of the National Academy of Sciences; **Charles M. Vest**, president of the National Academy of Engineering; and Harvey V. Fineberg, president of the Institute of Medicine. It was conferred at the Carnegie Science Awards ceremony at Carnegie Music Hall in Pittsburgh on May 3. Dr. Cicerone accepted the award on behalf of all three recipients.

On March 8, **C.P. Wong**, Dean of Engineering at the Chinese University of Hong Kong, on unpaid leave from Georgia Institute of Technology, was awarded the **International Dresden Barkhausen Award 2012** by the Materials Research Network Dresden, Fraunhofer IZFP Dresden, and Technische Universität Dresden. Dr. Wong received the award "for outstanding scientific results in applied research and development at frontier areas between physics, materials science, and electrical engineering, particularly for his seminal contributions to the discovery and understanding of novel physical properties of graphene and its applications in nanoelectronics." The award includes prize money of €10,000.

Steven Zinkle, chief scientist, Nuclear Science and Engineering Directorate, Oak Ridge National Laboratory, has been named a **2013 Fellow of the Materials Research Society** (MRS). Acknowledged for his "pioneering contributions to the understanding of radiation effects in materials and for advancing the scientific basis of performance limits for structural materials in advanced nuclear energy systems," Dr. Zinkle was formally recognized during the spring MRS meeting in April. No more than 0.2 percent of the current MRS members are elected fellows.

On April 29, six NAE members were elected to the National Academy of Sciences. They are **Kristi S. Anseth**, Distinguished Professor and HHMI investigator, Department of Chemical and Biological Engineering, University of Colorado Boulder; **Juris Hartmanis**, Walter R. Read Professor of Computer Science and Engineering Emeritus, Cornell University; **Stephen R. Quake**, HHMI investigator and Lee Otterson Professor, Departments of Bioengineering and Applied Physics, Stanford University; **John H. Seinfeld**, Louis E. Nohl Professor, California Institute of Technology; **James A. Sethian**, professor of mathematics, University of California, Berkeley; and **Éva Tardos**, Jacob Gould Schurman Professor of Computer Science, Cornell University.

On May 1, the US Department of Commerce's Patent and Trademark Office and the **National Inventors Hall of Fame** inducted four NAE members. **Arthur Ashkin**, retired member of the technical staff, Bell Laboratories, Lucent Technologies, for optical trapping: Ashkin invented optical trapping, also called optical tweezing, a process that traps molecules and macroscopic particles by using laser light. The technique utilizes radiation pressure, when light or other forms of radiation exert force on an object. The process has allowed for the study of small particles in many fields. **Donald L. Bitzer**, Distinguished University Research Professor, Computer Science Department, North Carolina State University, for plasma display: In the mid-1960s, Don Bitzer and Gene Slottow, faculty at the University of Illinois at Urbana-Champaign, and graduate student Robert Willson worked together to create the first plasma display. A new display was needed for the PLATO computerized learning system that had been created by Bitzer because traditional displays had no inherent memory, lacked high brightness and contrast, and flickered. **Irwin M. Jacobs**, director, Qualcomm Incorporated, and **Andrew J. Viterbi**, Presidential Chair Professor at the University of Southern California and president of the Viterbi Group, LLC, for code division multiple access (CDMA) technology: Drs. Jacobs and Viterbi, two of Qualcomm's cofounders, were major contributors to CDMA technology that is used in cellular telephone networks. CDMA now supports over 1.6 billion subscribers in developing and developed countries with voice and high-speed Internet access. It was standardized for North America in 1993.

NAE Honors 2013 Prize Winners

The NAE honors outstanding individuals for significant innovation, leadership, and advances in engineering. The 2013 award winners were honored at a black-tie dinner on February 19 at historic Union Station in Washington, DC. The recipients of the Charles Stark Draper Prize, the Fritz J. and Dolores H. Russ Prize, and the Bernard M. Gordon Prize accepted their awards before an audience of more than 350 guests, with NAE President **Charles M. Vest** and NAE Council Chair **Charles O. Holliday Jr.** at the podium. Also assisting in the presentations were James D. Shields, president and CEO, Charles Stark Draper Laboratory, Inc.; Roderick J. McDavis, president, Ohio University; and Harold S. Goldberg, advisor, Bernard M. Gordon Prize Committee.

Charles Stark Draper Prize

Left to right: Dr. Yoshihisa Okumura, Dr. Thomas Haug, Mr. Richard H. Frenkiel, Dr. Joel S. Engel, and Mr. Martin Cooper.

Martin Cooper, **Joel S. Engel**, **Richard H. Frenkiel**, Thomas Haug, and Yoshihisa Okumura were awarded the 2013 Charles Stark Draper Prize "for their pioneering contributions to the world's first cellular telephone networks, systems, and standards."

Cellular telephony is an exceptional technological achievement that has enabled people to communicate from virtually any location and access a myriad of information at the touch of a button. It connects people, provides security, and bridges information gaps.

The first limited form of mobile telephone service was provided by AT&T in 1946, and the initial ideas for cellular systems emerged at Bell Labs a year later. A lack of channels inhibited further exploration of these ideas until the late 1960s, when Bell Labs began planning activities for a "high-capacity" mobile telephone system. Engel and Frenkiel, with the late Phil Porter, were the earliest engineers involved in this work. They developed a plan for a network of low-power transmitters and receivers spread throughout a region in small coverage areas that came to be called cells, which allowed the expansion of service to millions of users with a limited number of channels. This plan resulted in a technical report, filed with the US Federal Communications Commission in 1971, presenting the design for what would become the Advanced Mobile Phone System (AMPS), the first cellular telephone system in the United States.

At the same time, at Nippon Telegraph and Telephone (NTT) Research Laboratories in Japan, Yoshihisa Okumura was laying the groundwork for a network system for widespread simultaneous cell phone use in that country. Through the investigation of precise propagation of radio waves in a high-frequency range, he found data that provided the foundation for a mobile model that could be used over wide areas that spanned cities, valleys, and mountains. In 1979, the NTT network became the world's first fully integrated commercial cell phone system and had the most advanced electronic switching.

Shortly after the cellular network was developed, Martin Cooper, who was working at Motorola at the time, unveiled the first portable hand-held cellular phone. After conducting in-depth research and filing several patents on technologies needed for the device, Cooper and his team produced a fully functional phone that utilized radio waves and frequency reuse to enable mobility and operability over a wide area. In 1973, Cooper made the first mobile telephone call on his cell phone prototype from a New York City street to a landline phone at Bell Laboratories. The phone call was answered by Engel.

In 1960 several Nordic countries had their own local mobile systems, but cell phone users were not able to transfer calls between towers. From 1970 to 1982, Thomas Haug worked to develop the Nordic Mobile Telephony (NMT) system, which provided analog service across the region's countries. In 1982, inspired by the successful Nordic example, he formed a research group to create a system that would enable users to place and receive calls anywhere in the world. By 1992 Haug and his colleagues had successfully developed the new digital high-quality and high-security mobile communication system called Global System for Mobile Communications (GSM), which permitted users to make and receive calls in and between any countries where the system was installed.

Acceptance Remarks by Richard Frenkiel

Richard H. Frenkiel

Our thanks to Dr. Vest, the Academy, and the Draper Laboratory for this great honor, and to our families, friends, and colleagues who have come here tonight to share this moment with us.

The creation of cellular telephony that we celebrate tonight was always more of a journey than a destination—a wide and winding road of creation and conflict traveled by thousands of pioneers doing many types of work over more than half a century.

We five reflect that diversity rather well. Yoshihisa Okumura provided the propagation data that we desperately needed to create the first cellular plans, and he pioneered a statistical approach that was perfect for a multicell system. Joel Engel was what the philosophers call a polymath—part researcher, worrying about delay spread and diversity; part systems engineer, shaping the cellular architecture; and part pamphleteer, sending passionate prose to the FCC. I worked with him on the architecture and the passionate prose, and then went on to the details—things like locating and handoff, and cell splitting, and standards. Thomas Haug had an international vision. He led the way to the Nordic Network, and then got all of Europe to agree to the Global System for Mobile Communications (GSM)—a remarkable achievement in the days before the European Union. Marty Cooper had a vision of portability. He took the cell phone from the trunk of his car to the palm of his hand, and started us on the path to truly personal communications.

And then a new generation of pioneers created 3G systems with

Internet access, and smartphones, and thousands of those useful "apps." Thanks to their vision and skill, there are now 6 billion cell phones in a world of 7 billion people, and the cell phone has become an important part of daily life.

Even in those early days when we were young, we walked that winding road with hundreds of cellular pioneers. More than a few of them were giants in our field, and too many of them are now gone. In our hearts, we share this moment with all of them. We know that for an engineer, the best life is to work with brilliant and creative colleagues, on problems that are fascinating and difficult, and to dream that someday the work you are doing will change the world. We are blessed to have walked with those early pioneers—those old friends—and to have shared with them that powerful dream and that wonderful work.

Thank you.

Fritz J. and Dolores H. Russ Prize

Left to right: Dr. Roderick J. McDavis, Dr. James J. Wynne, Dr. Rangaswamy Srinivasan, Mr. Charles O. Holliday Jr., and Dr. Charles M. Vest.

The 2013 Fritz J. and Dolores H. Russ Prize is awarded to **Rangaswamy Srinivasan**, James J. Wynne, and Samuel E. Blum "for the development of laser ablative photodecomposition, enabling LASIK and PRK eye surgery."

The development and application of ablative photodecomposition in corrective eye surgeries, known today as PRK and LASIK, has given millions of people throughout the world better vision. At the end of 2011, approximately 25 million people had undergone pulsed ultraviolet laser surgery to improve their eyesight, a procedure made possible by the collaborative efforts of Srinivasan, Wynne, and Blum. In 1981 while working at the IBM T.J. Watson Research Center, they discovered that pulsed laser radiation at 193 nm from an argon fluoride (ArF) excimer laser could etch animal tissue with submicron precision. Just as important, the laser caused no thermal damage to the adjacent tissue.

The initial discovery was made on November 27, 1981, when Srinivasan brought leftovers from his Thanksgiving meal into the lab. He irradiated turkey cartilage with pulses of light from the ArF (193 nm) excimer laser, and found it made a clean "incision" in the tissue. On subsequent days, he and Blum carried out additional turkey cartilage procedures under controlled conditions, measuring the laser's effect and the number of pulses used to produce incisions.

In parallel studies, Wynne conducted a comparable experiment using pulsed laser radiation at 532 nm from a Q-switched, frequency-doubled, Nd:YAG laser (532 nm), which did not result in a clean incision like that of the excimer laser. Instead, it left a burned and damaged region of tissue.

In 1982 and 1983, Srinivasan and Wynne began to study the effects of the ultraviolet excimer laser on human tissue through collaborations with cardiologists, ophthalmologists, dermatologists, and dental anatomists. Together with coworkers, the two men obtained fresh arterial tissue from a cadaver at New York Hospital (now New York–Presbyterian Hospital) and irradiated a segment of the aorta with 193 nm light from the ArF excimer laser and, separately, with 532 nm pulses from the Nd:YAG laser. The experiment yielded the same results as the turkey experiment: the excimer laser left no detectable evidence of thermal damage to the underlying and adjacent tissue while the 532 nm pulses caused visible thermal damage.

In 1983, Srinivasan, his IBM colleague Bodil Braren, and ophthalmologist Stephen Trokel published a paper on the potential for laser eye surgery in the *American Journal of Ophthalmology*. The publication detailed an excimer laser experiment on several enucleated calf eyes, which yielded excellent results and is regarded by the ophthalmic community as a seminal paper on laser refractive surgery.

Acceptance Remarks by Rangaswamy Srinivasan

Rangaswamy Srinivasan

I am delighted that Dr. James Wynne and I, along with the late Dr. Samuel E. Blum, have been selected to receive the **Fritz J. and Dolores Russ Prize** for 2013. This prize is notable for its emphasis on the impact of an engineering invention on a field of biology/medicine. (Let me add parenthetically that the field of bioengineering was not even identified as a separate discipline 50 years ago.) In 1999 when the Russ Prize was established, the National Academy of Engineering ruled that it would be dedicated to this field exclusively. This is only the seventh time that the prize is being awarded. I bring up this bit of history because of the three winners this time: one was trained as a laser physicist and the other two as a crystal chemist and a photochemist.

Our discovery in 1981 of the phenomenon of ablative photodecomposition of tissue by short, energetic pulses of far-ultraviolet radiation was not entirely an accident. It came about because it happened in a laser group that was pioneering the use of an excimer laser—a novelty at that time. I, the photochemist, noticed that a commercial polymer called Kapton, which resisted smooth etching by chemical solvents or solutions, could be easily drilled precisely and rapidly by a succession of focused laser pulses of 193 nm wavelength. It occurred to me that just as Kapton has a series of polyimide groups along its backbone, a protein is characterized by a succession of polyamide or peptide groups along its backbone. It was natural to try and see how well this relationship would enable the same laser at that wavelength to drill or etch solid animal tissue. We observed that the tissue was etched remarkably smoothly without any sign of thermal damage. Dr. Wynne then carried out the control experiment, which used a focused visible (green) laser at a similar fluence on the same animal tissue. It created excessive thermal damage. The experiment established that the excimer laser wavelength and fluence were key to the striking results we observed.

It is not surprising that it has taken many years for our experiments to be translated into a viable process for the etching of the human cornea. In the beginning, we needed to educate the practicing ophthalmologists in the chemical physics of ablative photodecomposition. Then a lot of engineering expertise was required to build a working machine, which was tested on rabbits, monkeys, and eventually on human eyes, with FDA supervision, of course. Today the reshaping of the human cornea by this process is widely practiced in developed countries. There you have the merging of physical science, biology, and engineering science—the synergy that the Russ Prize demanded!

Needless to say, we are truly overwhelmed by this honor. Thank you one and all!

Bernard M. Gordon Prize

Left to right: Mr. Charles O. Holliday Jr.; Mr. Harold S. Goldberg, Advisor, Bernard M. Gordon Prize Committee; Dr. Sherra E. Kerns; Dr. David V. Kerns Jr.; Dr. Richard K. Miller; and Dr. Charles M. Vest.

Richard K. Miller, David V. Kerns Jr., and Sherra E. Kerns were awarded the 2013 Bernard M. Gordon Prize "for guiding the creation of Olin College and its student-centered approach to developing effective engineering leaders."

Franklin W. Olin College of Engineering was founded in 1997 to prepare "students to become exemplary engineering innovators who recognize needs, design solutions, and engage in creative enterprises for the good of the world." Since the first students enrolled 10 years ago, Olin has become a significant agent for innovation in undergraduate engineering education with the goal of preparing the next generation for the complex, global challenges of the 21st century.

The F.W. Olin Foundation established Olin College to literally start over in higher education and develop a new paradigm for engineering education, addressing at once all the concerns raised about engineering education at the time. Furthermore, the purpose of the new institution is to "become an important and constant contributor to the advancement of engineering education in America and throughout the world." To ensure a fresh approach, Olin does not offer tenure, has no academic departments, offers degrees only in engineering, and provides substantial merit-based scholarships to all admitted students.

Richard Miller, as the college's president and first employee, provided the strategic vision and overall leadership of all aspects of the process of developing this new institution, including the shaping of its academic and institutional mission. David Kerns, founding provost, recruited Olin's faculty and deans, led the establishment of the collaborative faculty process resulting in Olin's three program curricula, and established employment relations for faculty in an environment without tenure. Sherra Kerns, as founding vice president of innovation and research, ensured the establishment of a gender-balanced community, led the efforts to achieve accreditation for the new programs, and was instrumental in creating a culture of innovation and intellectual vitality throughout the institution. All three also contributed to specific dimensions of the academic program, together with the faculty and students.

Acceptance Remarks by Richard K. Miller

First, we would like to express our deepest appreciation to Mr. Gordon for his generosity and commitment to advancing the field of engineering through innovations in education. It is a humbling experience to accept this award and our deep gratitude goes to the Academy and the selection committee. This award means a lot not only to us but also to the entire Olin community and many other educators in the field who are at the forefront of educational reform. I would also like to add my congratulations to the Draper and Russ Prize Awardees for their pioneering work in developing technologies that have changed and will continue to change our world.

Olin College is unique in higher education. It was the vision of Larry Milas, former president of the F.W. Olin Foundation and our first chairman of the board, who is here with

Richard K. Miller

us tonight. As he declared in our founding precepts, "Olin College is intended to be different, not for the mere sake of being different, but to become an important and constant contributor to the advancement of engineering education in America and throughout the world."

Olin was started from a blank slate in order to rethink engineering education from the ground up, and to address simultaneously all of the concerns about engineering education known at the time. You see, Larry and the other three foundation directors (including Bill Norden, our current board chair) believed that a new mindset is needed in higher education, not simply a new course or academic program here and there. He felt that higher education was too set in its ways and not sufficiently open to new ideas.

When I was selected in 1999 as Olin's first employee, I was nearly overwhelmed by the responsibility to deliver on these enormous expectations. My first task was to recruit an experienced and visionary leadership team to help shape this unique institution. Somehow I persuaded both David and Sherra Kerns to leave their leadership positions at Vanderbilt to join me. We all walked away from tenured positions at respected institutions in order to create an institution that, by design, will never offer tenure to its faculty. We also concluded that we would not create academic departments, in order to promote interdisciplinary thinking—like Bell Labs, 3M, Google, and Ideo. We concluded that design thinking and entrepreneurship would play a central role in the academic program. In fact, Olin is located adjacent to Babson College to enable mixing the DNA of gifted engineers with the most entrepreneurial new business leaders.

This Olin College project was so important that we all felt we must seek the help of the best minds everywhere in order to make the most of this opportunity—an opportunity that, incidentally, occurs much less frequently than once in a lifetime. As a result, I formed the President's Council to provide strategic advice. The first member of this council was **Bill Wulf**, who was then president of the NAE. Many other members of the NAE have since become engaged, and 20 percent of our current trustees are NAE members.

In addition, we visited 30 other universities and many corporations to seek advice on what changes in education they would recommend. We also shamelessly recruited faculty members away from many of the most respected universities in America. As you know, excellent universities—without exception—are always fundamentally about excellent people. So Olin College is, to a large extent, the result of contributions of the best ideas and people from around the nation. We owe any success we have had to many other institutions. In this sense, our success is your success, and we are deeply grateful for your support. We simply would not be here tonight without you.

However, the heavy lifting of conceiving, integrating, experimenting, balancing, and implementing the many new ideas that form the Olin learning model is the result of the endless hard work and innovation of our passionate faculty and student body. They deserve the lion's share of the credit for what exists today at Olin. Students, in particular, have played the key role in seeing what others did not see and showing us that we frequently underestimate what they are capable of doing. Without the help of our students, we would no doubt have a patchwork quilt of traditional courses instead of the holistic, integrated learning culture that now defines the Olin program.

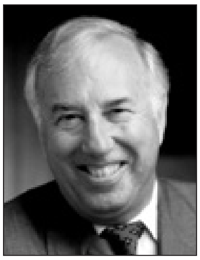
There is one person notably missing tonight and that is the late Michael Moody, founding dean of faculty at Olin College and a central figure in the development of Olin's academic program. We lost him three years ago to cancer but he remains alive in the pedagogy at Olin and in the hearts of his colleagues.

In the next decade, we are on a very deliberate mission to lead in the transformation of undergraduate engineering education. We have been visited by more than 200 universities in the last three years, by those who are interested in innovation in education. We aim to graduate more engineering innovators and leaders to address the grand challenges our world now faces and to drive the creation of jobs requiring imagination, innovation, and a deep knowledge of engineering and science. This prize could not have come at a better time to accelerate our efforts in this cause.

And finally, I know I speak for David, Sherra, and the members of the greater Olin community when I thank our families for their support.

Again, we are enormously grateful to the Academy for this great honor. Thank you.

NAE President, Treasurer, and Councillors Elected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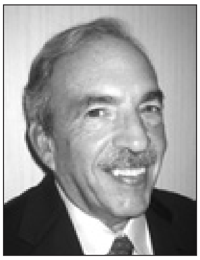
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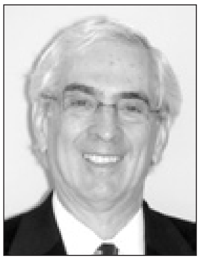
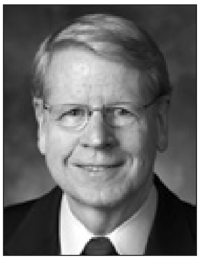

Paul Citron


Uma Chowdhry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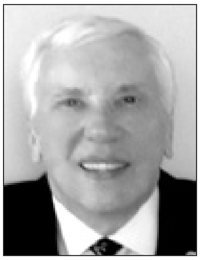
C. Paul Robinson


Charles M. Vest


Linda M. Abriola


Ruth A. David


Charles Elachi

This spring, the NAE elected its president and treasurer, reelected an incumbent councillor, and elected three new councillors. All terms begin July 1, 2013.

Elected to a six-year term as NAE president was **C. D. (Dan) Mote, Jr.**, Regents Professor and Glenn L. Martin Institute Professor of Engineering in the A. James Clark School of Engineering at the University of Maryland (UMD) and past president of UMD. Elected to a four-year term as NAE treasurer was **Martin B. Sherwin**, retired vice president of W.R. Grace.

Paul Citron, retired vice president of technology policy and academic relations at Medtronic, Inc., was reelected to a three-year term as councillor. Newly elected to three-year terms as councillors were **Uma Chowdhry**, senior vice president and chief science and technology officer emerita of the DuPont Company Experimental Station; **David E. Daniel**, president of the University of Texas at Dallas; and **C. Paul Robinson**, president emeritus of Sandia National Laboratories.

On June 30, 2013, **Charles M. Vest** will complete a six-year term of service as NAE president. C. D. (Dan) Mote, Jr., will complete a four-year term of service as treasurer. **Linda M. Abriola**, dean of engineering at Tufts University; **Ruth A. David**, president and chief executive officer of ANSER (Analytic Services Inc.); and **Charles Elachi**, director of the Jet Propulsion Laboratory and vice president of California Institute of Technology, will complete six continuous years of service as councillors, the maximum allowed under the Academy's bylaws. Dr. Vest, Dr. Mote, Dr. Abriola, Dr. David, and Dr. Elachi were recognized in May for their distinguished service and other contributions to the NAE.

2013 National Meeting

NAE members and guests gathered at the Beckman Center in Irvine, California, on February 7 for the 2013 NAE National Meeting, which was held in honor of **Charles M. Vest**. After the morning's business session, the members were joined by 155 students from the following local schools: Firebaugh and Lynwood High Schools in Los Angeles County; High Tech High (HTH) and High Tech Middle (HTM), HTH International, and HTH and HTM Media Arts, all in San Diego; HTH and HTM Chula Vista; and HTH and HTM North Country in San Marcos, as well as students from the University of California, Irvine (UCI) California Alliance for Minority Participation (CAMP) Program.

NAE chair **Charles O. Holliday Jr.** welcomed the members, guests, and students to the symposium with brief remarks encouraging the students to consider the impact they can have on the world through a career in engineering. Vice President **Maxine L. Savitz** chaired the technical session and began by introducing keynote speaker **Yannis C. Yortsos**, Dean of the Viterbi School of Engineering at the University of Southern California (USC). In his talk on "The NAE Grand Challenges: An Inspiration for Our Times," Dean Yortsos noted that the concept of engineering Grand Challenges was formulated by an NAE committee in 2007 and has proven to be an effective vehicle to inform policymakers, the public, students, and their parents and advisors on the critical importance of engineering to solving significant challenges that face society. Together with partners at Duke University and Olin College, Dr. Yortsos has helped promote the Grand Challenges by cohosting the inaugural NAE Grand Challenges Summit at Duke University in 2009 and its follow-up at USC in 2010. The first summit led to the creation of the Grand Challenge Scholars Program for undergraduate engineering schools across the nation.

Dr. Mote with UCI students

Roger McCarthy talking with students

The program continued with Gilbreth Lectures on issues related to the Grand Challenges, presented by young engineers who had participated in the NAE's Frontiers of Engineering symposia. Ronald Azuma, Augmented Reality Leader, Intel IXR, spoke on "Augmented Reality: Meaningful Connections and Compelling Experiences." Manu Parashar, Principal Power Systems Engineer, Alstom Grid, spoke on "Synchrophasor Wide-Area Measurement and Control." Sossina Haile, Carl F. Braun Professor of Materials Science and of Chemical Engineering, California Institute of Technology, spoke on "Material Solutions for Energy Conversion and Storage: Fuel Cells and Solar Fuel Generators." And Riley Duren, Chief Systems Engineer, Earth Science and Technology, Jet Propulsion Laboratory, spoke on "Geoengi-

Maxine Savitz with students

The High Tech High Group

neering and Climate Intervention: What We Need to Know."

The day ended with a reception for members and guests.

Students were invited to comment on their experience at the meeting. UCI student Walter Cisneros observed:

> It was a great opportunity to approach individuals that have accomplished their educational and career goals. It was amazing to spend time with the innovators of the bases of what now we call technology. For example, I talked to engineers that helped with the design of a challenger spacecraft and an engineer that helped with the design of the first intercontinental ballistic missile. Engineers like them shaped the world and… our country. The opportunity to meet engineers of such…magnitude has radically changed my perspective on how important it is to become a successful engineer and to make a positive impact in our society.

Brian Morey, another UCI student, wrote:

> I found the NAE symposium to be a great experience and an excellent networking opportunity…. I found the presenters to be welcoming and more than willing to talk about their current projects after they gave their presentations. One of the presenters, Dr. Ronald Azuma, even provided me with a paper that detailed how computers tracked objects with their camera after I asked him several questions about his presentation. I talked with several other attendees as well and was surprised at how approachable they were and their willingness to share their experiences in the field of engineering. Unlike conferences where I always felt a disconnect between representatives and students, I found it refreshing to meet professors that were willing to just talk and share their knowledge and experiences.

And Sharon Tamir, a student of the Gary and Jerri-Ann Jacobs HTH Graduating Class of 2016, sent a letter (reproduced on page 70) detailing the highlights and lasting impressions of her experience at the meeting.

The NAE National Meeting is an opportunity to inspire and encourage students, especially those from local high schools, to become engineers. The next National Meeting is scheduled for February 6, 2014, at the Beckman Center. Mark your calendar now and plan on coming and reaching out to the students about your experiences in engineering.

February 9th, 2013

The Gary and Jerri-Ann Jacobs

HIGH TECH HIGH

2101 Constitution Ave NW
Washington, DC 20418

Subject: Thank You Letter to National Academy of Engineers

Dear National Academy of Engineers,

During the presentations given on the 7th of February, at the national meeting in Irvine, Ronald Azuma stated, "anything that involves communication is fundamental". That whole meeting was a frenzy of equations, theories, connections and ideas that were so clearly and directly communicated to me and the 102 other students that came from High Tech High. For that, I thank you all.

We were humbled by the presence of such high-class businessmen as Charles O. Holliday Jr. and 'engineering girls' such as Maxine L. Savitz. Yannis C. Yortos succeeded in emphasizing the importance of the engineering community, the challenges that must be tackled, and the influence that "two-and-a-half greeks" can have on the scientific world.

With Ronald Azuma we were able to explore the technology that will eventually lead to the movie Total Recall becoming a reality and the future of medical procedures and education via augmented reality. Manu Parashar highlighted the unpredictability of the weather and electrical generators, and how phasers - unlike the ones the aliens have - can not only tell when there is a disruption in a complex electrical system, but can *also* predict one.

Sossina M. Haile was so savvy in her subject that she was capable of explaining how she used non-stoichiometric ceria to isolate hydrogen and oxygen molecules in a way that my peers and I could understand with only a rudimentry understanding of chemistry. Last but not least, with humor and enthusiasm, Riley Duren taught us the complexity behind global warming and geoengineering, how NASA plays a role in it, and what separates engineers from the scientists at Aperture: engineering is not just *how*, but *should you* and *why*.

The chance to get so close to people who can really make a difference in the world, the role models we dream of becoming, was an amazing experience and opportunity that is not easily duplicated. I know I speak for everyone who had the honor of attending when I say that I will treasure such an opportunity for my entire academic - and maybe even STEM - career.

In short, thank you.

Sincerely,

Sharon Tamir

Sharon Tamir

Strong/Swaaley Team
Gary and Jerri-Ann Jacobs High Tech High
Graduating Class of 2016

HIGH TECH HIGH . 2861 Womble Road, San Diego, CA 92106 . 619 243-5000 . www.hightechhigh.org

Global Grand Challenges Summit Held in London

In March, the NAE and the engineering academies of the United Kingdom and China, with principal support from Lockheed Martin, cohosted the first Global Grand Challenges Summit (GGCS) in London. More than 400 people participated in the 2-day event with the goal of identifying opportunities for global cooperation on engineering innovation and education to address common technological goals.

Also in attendance were 60 students from around the world who were invited to attend Student Day just before the GGCS. They were asked to choose one of six NAE Grand Challenges for Engineering and develop a pitch for one way of addressing it. Each team presented its proposal before a panel of expert judges and the winner, TeleHealth Express aimed at streamlining medical care, was showcased at the Summit.

GGCS panel sessions focused on six themes: sustainability, health, education, technology and growth, enriching life, and resilience. Summit speakers included Caltech's **Frances Arnold**, Imperial College professor Lord Darzi, former DARPA head and current Google/Motorola executive Regina Dugan, Stanford University president **John Hennessy**, prolific inventor **Dean Kamen**, and economist Jeffrey Sachs, among others.

Additional highlights included plenary addresses from genome pioneer J. Craig Venter and Microsoft chairman **Bill Gates**, presentation of the Global Grand Challenges Video Contest winners by NASA's **Charles Elachi** and entertainer Will.i.am, and announcement of the Vest Scholarships in honor of NAE President **Charles M. Vest**. Also announced at the event was a new joint project between the US National Science Foundation and the UK Engineering and Physical Sciences Research Council to fund transatlantic research with the goal of providing all people with access to clean water.

The Video Contest was cosponsored by IBM and Genentech, and the Student Day by Microsoft.

International Scholarship Focused on Global Grand Challenges

On March 13, 2013, at the inaugural Global Grand Challenges Summit (GGCS) in London, eight US universities announced the establishment of Vest Scholarships at their institutions. The new scholarship program, named after outgoing NAE President **Charles M. Vest**, will foster international collaborations among graduate students whose studies focus on tackling some of the world's biggest challenges. The scholarship has been endorsed by both the NAE and the UK Royal Academy of Engineering.

The participating universities are leaders in research to address the NAE Grand Challenges for Engineering (www.engineeringchallenges.org), 14 goals with the potential to dramatically improve life in the 21st century, identified in 2008 by a blue-ribbon committee of leading technological thinkers and doers. The challenges are the inspiration for the GGCS.

"The NAE Grand Challenges for Engineering address global issues that transcend national boundaries," said **Yannis C. Yortsos**, dean of the University of Southern California Viterbi School of Engineering. "They are timely, inspirational, and interdisciplinary. Their solutions are also within reach in this time of exponential technology gains. The Vest Scholarships will provide the glue that will enable the engagement of the international engineering and scientific communities in pursuits that will benefit all of humanity."

The Grand Challenges are already being incorporated into education at all levels—including an undergraduate Grand Challenge Scholars Program at several US colleges and universities—and Dr. Vest has been influential in raising their visibility.

"All of the sponsoring schools were unanimous in naming the scholarships for Dr. Vest," said Tom Katsouleas, dean of engineering at Duke University. "His leadership and championing of the Grand Challenges, and the role of the engineering profession, has been inspirational."

In the first year, applicants from schools whose students attended the Global Grand Challenges Summit will be eligible for the scholarships. In later years, the program will be expanded to additional schools.

"This is like a reverse Rhodes

Scholarship," said Katsouleas. "It gives select international graduate students the opportunity to pursue potentially world-changing ideas at top US universities."

Participating schools are Duke University, California Institute of Technology, Olin College, University of Southern California, University of Washington, Illinois Institute of Technology, Massachusetts Institute of Technology, and North Carolina State University. Selected students will receive an expense-paid year to pursue research opportunities related to the 14 NAE Grand Challenges for Engineering at one of those institutions.

Additional information about the Vest Scholarships is available at vestscholars.org.

2013 German-American Frontiers of Engineering Held at Beckman Center

The 2013 German-American Frontiers of Engineering Symposium (GAFOE) took place April 26–28 at the Arnold and Mabel Beckman Center in Irvine, California. The NAE partners with the Alexander von Humboldt Foundation to organize this event, the first of the bilateral Frontiers of Engineering programs, started in 1998. The symposium organizing committee was cochaired by **Cynthia Barnhart**, associate dean of engineering and professor of civil and environmental engineering at the Massachusetts Institute of Technology, and Peter Moser, head of innovative power plant technology R&D at RWE Power AG.

Modeled on the US Frontiers of Engineering Symposium, GAFOE brings together emerging engineering leaders ages 30–45 from German and US companies, universities, and government with the goal of providing a forum for them to learn about leading-edge developments in a range of engineering fields and thus facilitating interdisciplinary transfer of knowledge and methodology. The bilateral Frontiers symposia also help build cooperative networks of younger engineers across national boundaries.

The four topics covered at this year's GAFOE were additive manufacturing, transport in complex systems, biomass conversion, and materiomics. Presentations by two Germans and two Americans in each area covered topics such as design for additive manufacturing, collective motion from active matter to swarms in natural engineered systems, production and utilization of green hydrogen, and innovative biomimetic materials inspired by plants. The program, list of attendees, and presentation slides are available at the GAFOE link at www.naefrontiers.org.

As is typical with bilateral FOE meetings, there was a poster session on the first afternoon where attendees presented their research or technical work to each other. The posters remained on display throughout the meeting and prompted many conversations and continued exchanges.

The dinner speech was delivered by **Frances H. Arnold**, Dick and Barbara Dickinson Professor of Chemical Engineering, Bioengineering, and Biochemistry at the California Institute of Technology. It was particularly meaningful for her to give the dinner address as she was the first speaker at the very first US Frontiers of Engineering symposium in 1995. She spoke about how the ability to synthesize genomes will enable researchers to "compose" in the biological world and create useful things that can alleviate some of the world's grand challenges.

On the second afternoon, attendees took a beach and nature walk and learned about local marine life and the history of Laguna Beach. Everyone enjoyed the opportunity to experience firsthand the beautiful weather and views of southern California's Pacific coast as well as the chance for interactions in an informal setting.

Funding for the meeting was provided by The Grainger Foundation and the National Science Foundation. The next GAFOE meeting will take place in 2015 in Germany, and Drs. Barnhart and Moser will continue to serve as cochairs.

The NAE has additional bilateral Frontiers of Engineering programs with Japan, India, China, and the European Union. In 2014, a joint Frontiers of Science and Engineering symposium organized with the National Academy of Sciences will be held in Brazil. All the FOE symposia bring together outstanding engineers from industry, academe, and government at a relatively early point in their careers (all participants, including speakers and organizers, are 30–45 years old). The meetings provide an opportunity for them to learn about developments, techniques, and approaches at the forefront of fields other than their own, something that has become increasingly important as engineering has become more interdisciplinary. The program also facilitates the establishment of contacts and collaboration among the next generation of engineering leaders.

For more information about this activity, go to www.naefrontiers.org or contact Janet Hunziker in the NAE Program Office at (202) 334-1571 or jhunziker@nae.edu.

NAE Regional Meetings

Symposium on Online Learning and How Technology May Change Higher Education, Held at Stanford University

Massive open online courses (MOOCs) were front and center at a symposium held in conjunction with the National Academy of Engineering (NAE) regional meeting March 5 at Stanford University's School of Engineering. NAE Vice President **Maxine L. Savitz** opened the meeting, noting that the NAE is preparing to celebrate its 50th anniversary in 2014, and Stanford Engineering Dean **Jim Plummer** followed, introducing the often-controversial topic of online learning.

"I've heard fear expressed that higher education as we know it is coming to an end. I've also heard that online learning is going to reinvent higher education in a new and better form," said Plummer. "It's clearly a rapidly evolving field."

"It's like 1993 in the history of the World Wide Web," agreed **David Patterson**, a University of California, Berkeley, computer science professor who cotaught one of the early MOOCs.

Patterson was one of six panelists discussing "Online learning: Will technology transform higher education?" Most agreed that MOOCs, which have expanded from three classes offered by Stanford in 2011 to hundreds offered by dozens of universities, offer unprecedented opportunities for people who would not otherwise have access to high-quality higher education. Panelists also said they are encouraged by widespread faculty interest in examining ways to improve their teaching.

"People are thinking about the classroom experience in a more careful and meticulous way," said panelist John Mitchell, Vice Provost for Online Learning at Stanford.

But opinions varied widely about the future of MOOCs, how learning will evolve as a result of new technologies, and whether technology is even a driving force behind current shifts in higher education.

Technologies like broadband Internet and social media that have helped make MOOCs possible "reduce the friction that is holding together the building blocks" of higher education, said panel moderator Bernd Girod, Senior Associate Dean for Online Learning and Professional Development at Stanford Engineering. "MOOCs could be to higher education what Napster was to the music industry," he said, referring to the music-sharing system that helped change how music is purchased and consumed. He added that online technologies have repeatedly enabled unbundling and disrupted traditional business models.

Mitchell Stevens, an associate professor of education at Stanford, said the move to online education is driven not by technology but by factors such as contracting state budgets, which put pressure on many colleges to reduce costs even as they face growing scrutiny of their performance. But he added that digital educational delivery mechanisms enable college educators to measure and improve performance.

At the same time, MOOCs pose new challenges for educators because of the lack of one-on-one faculty-student interaction. Tina Seelig, executive director of the Stanford Technology Ventures Program who recently taught her second online session of "A Crash Course in Creativity," said the biggest challenge she faced was the extreme precision the online class required. "When you're teaching an online class, if you're not exactly clear about what you want [from students], you don't get exactly what you expect," she said.

Another challenge is that only a small percentage of students who enroll in a MOOC actually complete it. One way to change that is to offer students course credit for successful completion, said David Stavens, president and cofounder of online education startup Udacity. The company recently partnered with San Jose State University to offer three classes for credit for $150 each, the first such agreement between a MOOC provider and a university.

Jennifer Widom, chair of Stanford's computer science department, recently taught her second "Introduction to Databases" MOOC. Although she said she finds it gratifying to be able to reach tens of thousands of people who can't enroll in her Stanford course, she and others question whether the MOOC model in its current form is sustainable.

Some wonder how the numerous businesses that have sprung up around MOOCs will stay afloat while delivering a free product. Others point out the potential challenges of verifying student identity and preventing cheating, especially if course credit is offered. Some worry that the growth of online education could endanger small colleges; others see an opportunity for institutions offering top-tier programs to license course content to others and improve the quality of education on a large scale.

Most agree, however, that online education in some format holds enormous promise. "There are lots of opportunities ahead," said Girod. "This is an exciting time for higher education."

2013 NAE Southeast Regional Meeting Summary

Gen. Keith Alexander delivering the keynote speech at the March 28 NAE regional meeting on cyber security.

The Georgia Institute of Technology hosted the NAE's 2013 Southeast regional meeting on April 28 in Atlanta. Scheduled adjacent to a cyber security–related conference the next day, featuring university CIOs and the FBI, the two events were jointly billed as the Georgia Tech Cyber Security Symposium.

Georgia Tech President Bud Peterson and Provost **Rafael Bras**, together with NAE Vice President **Maxine Savitz**, welcomed a capacity crowd to the meeting, which was free and open to the public. College of Computing Dean **Zvi Galil** served as emcee.

The afternoon was devoted to a critically important issue facing both the United States and the world: cyber security. Gen. Keith Alexander, director of the National Security Agency, chief of Central Security Service, and commander of US Cyber Command, delivered a wide-ranging keynote address titled "US Cyber Security: Key Issues for Our Future."

He touched on the variety and nature of cyber threats facing government and industry, as well as other challenges facing those charged with protecting digital assets, such as the need to balance effective security with individual and organizational privacy rights. The general also offered strong encouragement to security students in attendance.

"We need a significantly larger workforce in cyber security," Alexander said. "That's where you—Georgia Tech—come in. This is going to be one of the biggest growth areas for the next several years. For all of you [studying cyber security] here today, you're in the right place. If you are good in this area, you'll have no problem getting a job."

Attendees then got an inside look at cyber security from several perspectives. First was a session featuring startup companies and/or research efforts that originated at Georgia Tech:

- Pindrop Security (Mustaque Ahamad and Patrick Traynor, School of Computer Science), which is dedicated to "securing the converged telephony infrastructure"
- BISmark (Nick Feamster, School of Computer Science), which promotes Internet transparency through effective home network monitoring
- Damballa (Wenke Lee and Merrick Furst, School of Computer Science), which conducts Internet-scale monitoring of cyber attack command-and-control infrastructures
- Apiary (Andrew Howard, Georgia Tech Research Institute), which performs automated and correlated malware analysis for the corporate community
- Whisper Communications (Steve McLaughlin, School of Electrical and Computer Engineering), which focuses on security of mobile payments

Next were presentations on cyber security startups with more tangential relationships to Georgia Tech, either with significant contributions by current or former students or, in the case of Social Fortress, having progressed through an Institute business development program called Flashpoint:

- Bluebox (David Dewey), which focuses on protecting corporate information on mobile devices
- CodeGuard (David Moeller), which provides cloud-based website backup
- Social Fortress (Adam Ghetti), which controls personal and/or enterprise data through a single sign-on portal

The regional meeting concluded with an entertaining exchange on cyber security policy, featuring two White House veterans. Arguing from the right side of the aisle was Stewart Baker, partner in the Washington law firm of Steptoe and Johnson and a former head of the Department of Homeland Security Policy Directorate under President George W. Bush. On the left was Peter Swire, C. William O'Neill Professor of Law at Ohio State University, who has served as an advisor on cyber security to Presidents Bill Clinton and Barack Obama. The session was moderated by Annie Anton, chair of Georgia Tech's School of Interactive Computing.

The keynote speech and meeting sessions are available online at www.cc.gatech.edu/events/2013-cyber-security-symposium.

Symposium on Shale Gas: Implications for America's Regional Manufacturing Economies, Held at Carnegie Mellon University

Shale gas production in the United States is increasing at a rapid rate and is expected to provide half of the country's natural gas supply by 2040. This low-cost, abundant resource has already stimulated a petrochemical manufacturing renaissance in the United States, and there is the hope and expectation that more benefits will be realized in other manufacturing sectors and in transportation. However, adequate infrastructure is essential if the downstream benefits of shale gas are to be realized. And every stage—from extraction to distribution, processing, and end use—creates environmental impacts, for which a stable and adequate regulatory environment is required.

It was especially timely, then, that the National Academy of Engineering and Carnegie Mellon University's Willard E. Scott Institute for Energy Innovation convened a symposium on Shale Gas: Implications for America's Regional Manufacturing Economies on April 4, 2013. Carnegie Mellon's Pittsburgh campus provided an excellent and fitting venue in light of the rapid and dynamic development of gas resources in the western Pennsylvania portion of the Marcellus Shale Formation.

David Dzombak, Carnegie Mellon's Walter J. Blenko Sr. University Professor of Civil and Environmental Engineering, welcomed 275 attendees and served as moderator. NAE Vice President **Maxine Savitz** welcomed participants on behalf of the Academy.

Jared Cohon, Carnegie Mellon's president, set the stage for the remainder of the symposium with an overview of the technical, economic, and political complexities of shale gas development as well as the uncertainties faced by industry, regulators, local communities, and landowners. He stressed the importance of finding balanced solutions, which are more likely to be produced through collaboration and cooperation in pursuing shared goals.

The first of three panels focused on industrial development. Moderated by Andrew Gellman, Head and Lord Professor of Chemical Engineering at Carnegie Mellon and codirector of the Scott Institute, the panel featured Gerald Holder, US Steel Dean of Engineering and professor of chemical and petroleum engineering at the University of Pittsburgh; Anthony Cugini, director of the US Department of Energy's National Energy Technology Laboratory; Peter Molinaro, vice president for North America Government Affairs at Dow Chemical; and Russell Crockett Jr., senior vice president of TPC Group, a leader in the petrochemical industry. The range of opportunities and challenges for the downstream use of shale gas were explored in a spirited discussion with many questions from the audience.

The availability of relatively inexpensive shale gas has significant implications for American manufacturing. Formations with "wet gas" (natural gas with relatively high concentrations of ethane, propane, and butane), which include the Marcellus Shale, can be a source of feedstock for the petrochemical industry. Processing this wet gas requires very expensive infrastructure. Thus, the most likely scenario will see such gas transported to the Gulf Coast, which has extensive petrochemical industry and facilities.

Shale gas can also be used to meet industrial energy needs. This is surely a benefit for manufacturers, although it is questionable that inexpensive and abundant energy would, by itself, lead to a manufacturing renaissance in parts of America.

Particularly intriguing is the so-called "Third Wave." In this scenario, petrochemicals produced from relatively cheap shale gas and used as inputs to other industrial processes could spur significant growth in regional manufacturing. The combination of inexpensive inputs, proximity to customers, and access to technological leadership might induce companies to return to America from the low-cost countries to which they moved.

The second panel, on national gas transportation, was moderated by Caren Glotfelty, senior director of the Environmental Program at the Heinz Endowments. The panelists were Ellen McLean, interim CEO of the Port Authority of Allegheny County; James McCarville, executive director of the Port of Pittsburgh Commission; Richard Kauling, manager of the Global Gaseous Fuels Technical Resource Center at General Motors; William Chernicoff, manager of energy and environmental research at Toyota Motor North America; and Bradley Mallory, executive deputy secretary for administration of the Pennsylvania Department of Transportation.

Compressed natural gas (CNG) is an attractive fuel for vehicle fleets, such as city buses. The economic savings and environmental benefits may justify the investment required for storage, refueling, and transportation facilities. Broader use of CNG, beyond captive fleets, is more uncertain. Shale gas may play an important role as a feedstock for hydrogen fuel-cycle vehicles, although the infrastructure required is a major hurdle. Nevertheless, the aggressive national fuel economy standards may provide a very strong impetus.

The third panel, on environmental impacts, was moderated by Granger Morgan, head and Lord University Professor of Engineering and Public Policy at Carnegie Mellon and director of the Scott Institute. The panelists were Andrew Morgan, corporate director of energy and environmental policy at EQT; Jeanne VanBriesen, professor of civil and environmental engineering at Carnegie Mellon; Allen Robinson, head and Lane Professor of Mechanical Engineering at Carnegie Mellon; and Paul King, president and CEO of the Pennsylvania Environmental Council.

Shale gas production has both air and water impacts, both of which were reviewed by the panel. As research and debates over regulation proceed, there is an emerging sense that environmental effects can be contained through the adoption and use of best practices. The Center for Sustainable Shale Gas Development (CSSD) is a promising new initiative; its interim executive director, Mr. Place, explained that this multisector organization will seek to promote best practices.

Professor Dzombak closed the symposium with thanks to Deborah Stine, executive director of the Scott Institute and professor in the practice of engineering and public policy at Carnegie Mellon, for her outstanding effort in organizing the event.

An Engineer's Oath

We are pleased to reprint here an Engineer's Oath administered at the Newark College of Engineering (now the New Jersey Institute of Technology) by Dr. Allan R. Cullimore, president of the college from 1920 to 1947. We present it as an inspiring example of guiding principles that are as true now as they were then; with a bit of updating in the language this document may serve as a template for today's engineers.

Thanks are due to **Albert A. Dorman** for bringing this oath to our attention. We are also grateful to the NJIT staff for their assiduous efforts to provide more information about it; unfortunately, they and we were unable to determine the authorship of the oath or its history. We would be glad to hear from you if you have such information.

Administering of the Engineer's Oath

DR. ALLAN R. CULLIMORE

As an engineer: I have a deep, abiding respect and faith in the ideals of my chosen profession; I believe that membership in it entails the most solemn obligations—obligations that I am eager and earnest to fulfill; I believe that, as a member of this profession, I have a vital and personal responsibility to act for the benefit of mankind, to render usable nature's vast material reservoirs and her latent energies.

As an engineer: I believe that the duties and the responsibilities of the profession rest more heavily upon me because of the traditions, the heritage, and the accumulated experiences passed down to me by members of the same profession in earlier generations, and I believe I should dedicate my efforts to the furtherance and development of these ideals and the dissemination of our philosophy and practice to younger men of the profession, that it may warrant a high place in the field of human endeavor.

As an engineer: I believe, in common with all men, that I should strive for the common good, interest myself in the service of humanity, and render to my fellow man and to my community without thought of material recompense such service as will be for the greatest public good.

As an engineer: I further believe that my profession requires in its very nature particular sensitivity to moral obligations and to the broadest human welfare and progress, that our world, with its material things and things of the mind and of the spirit, may be a better place to live in.

All these things I do truly believe and to these principles I solemnly commit myself.

Conferring of Degrees

FREDERICK L. EBERHARDT
President of the Board of Trustees

Recessional

NAE Receives $500,000 Gift from W.M. Keck Foundation to Name and Endow the Simon Ramo Founders Award

The National Academy of Engineering has received a $500,000 gift from the W.M. Keck Foundation to endow and name the Founders Award after **Simon Ramo**, the only surviving founding member of the NAE. The announcement was made on May 7, Dr. Ramo's 100th birthday.

Dr. Ramo was a member of a committee of 25 that in 1964 advocated for establishing the NAE, which operates under the congressional charter that established the National Academy of Sciences. The Founders Award was established the following year to honor an outstanding member or foreign associate who has upheld the ideals and principles of the NAE through professional, educational, and personal accomplishment. The award is presented at the NAE's annual meeting each October.

"The Keck Foundation is pleased to make this gift in honor of Si Ramo," said Robert Day, chairman and CEO of the W.M. Keck Foundation. "The naming of this award for Si is a fitting way to express our appreciation for his championing of cutting-edge scientific and medical research and for his service as a valuable advisor to our grantmaking."

"It is most gratifying to name this prestigious award after Si Ramo, who was so instrumental in the creation of the NAE almost 50 years ago," said **Charles M. Vest**, president of the National Academy of Engineering. "The NAE is very grateful to the W.M. Keck Foundation for helping us honor this great man by endowing this award."

U.S. News Announces STEM Leadership Hall of Fame Award Winners

U.S. News & World Report announced the winners of the 2013 U.S. News STEM Leadership Hall of Fame Awards. Of the five honorees chosen from a group of outstanding nominees representing the fields of science, technology, engineering, and math, two are NAE members: **Charles M. Vest**, NAE president, and **Irwin M. Jacobs**, founding chairman and CEO emeritus of Qualcomm Inc. *U.S. News* editor Brian Kelly said: "All of these award winners have not only been pioneers in their own disciplines but also have helped lead the national effort to better prepare students and workers in the STEM fields." The Hall of Fame recipients will be honored in a special ceremony on Wednesday, June 19, at the U.S. News STEM Solutions 2013 National Conference in Austin, Texas.

Calendar of Meetings and Events

June 18–19	NAE Regional Meeting Case Western Reserve University, Cleveland, Ohio
June 27–28	Council of Academies of Engineering and Technological Sciences Budapest, Hungary
July 1	Presidential Transition
July 16	NAE-USIP Roundtable on Technology, Science, and Peacebuilding USIP Headquarters, Washington, DC
August 4–5	NAE Council Meeting Woods Hole, Massachusetts
September 12–13	Workshop on Energy Ethics in Graduate Education and Public Policy: Enhancing the Conversation
September 19–21	US Frontiers of Engineering Wilmington, Delaware (Hosted by DuPont)
September 26–27	Diversity Impediments Workshop

All meetings are held in National Academies facilities in Washington, DC, unless otherwise noted.

In Memoriam

YVONNE C. BRILL, 88, aerospace consultant, died on March 27, 2013. Ms. Brill was elected to the NAE in 1987 "for important and original contributions to spacecraft propulsion."

FRANCIS H. CLAUSER, 99, Clark B. Millikan Professor Emeritus of Engineering, California Institute of Technology, died on March 3, 2013. Dr. Clauser was elected to the NAE in 1970 "for innovations in engineering research and education."

W. GENE CORLEY, 77, senior vice president, CTL Group, died on March 1, 2013. Dr. Corley was elected to the NAE in 2000 "for leadership in raising the standards of the engineering profession for construction of buildings and bridges."

WILLIAM C. HITTINGER, 90, consultant and retired executive vice president, RCA Corporation, died on March 17, 2013. Mr. Hittinger was elected to the NAE in 1976 "for contributions to high-frequency transistors and management in industries involving advanced technology."

LESTER C. KROGH, 87, retired senior vice president, research and development, 3M, died on January 25, 2013. Dr. Krogh was elected to the NAE in 1988 "for contributions to the development and application of unique materials, and for leadership of innovative research."

JOHN W. LANDIS, 95, chairman, Public Safety Standards Group, died on March 16, 2013. Dr. Landis was elected to the NAE in 1981 "for contributions to and leadership in the design and construction of advanced nuclear steam supply systems and nuclear power standards."

THEODORE ROCKWELL, 90, retired founding partner and board member, MPR Associates, died on March 31, 2013. Dr. Rockwell was elected to the NAE in 2001 "for contributions to the development of reactor shielding technology and nuclear-power reactor safety."

IAN M. ROSS, 85, president emeritus, AT&T Bell Laboratories, died on March 10, 2013. Dr. Ross was elected to the NAE in 1973 "for individual contributions to semiconductor electronics and in leadership to the nation's manned spaceflight program."

WILLEM "PIM" STEMMER, 56, CEO, Amunix Inc., died on April 3, 2013. Dr. Stemmer was elected a foreign associate of the NAE in 2012 "for co-invention of directed evolution and development of protein therapeutic platforms."

MILTON E. WADSWORTH, 90, professor of metallurgy emeritus, Department of Metallurgical Engineering, University of Utah, died on January 31, 2013. Dr. Wadsworth was elected to the NAE in 1979 "for contributions in the field of hydrometallurgy."

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 NW–Keck 360, Washington, DC 20001. For more information or to place an order, contact NAP online at <*www.nap.edu*> or by phone at (888) 624-6242. *(Note: Prices quoted are subject to change without notice. There is a 10 percent discount for online orders when you sign up for a MyNAP account. Add $6.50 for shipping and handling for the first book and $1.50 for each additional book. Add applicable sales tax or GST if you live in CA, CT, DC, FL, MD, NY, NC, VA, WI, or Canada.)*

Building the Ohio Innovation Economy: Summary of a Symposium. Since 1991, the National Research Council (NRC)'s Board on Science, Technology, and Economic Policy (STEP) has undertaken a program of activities to improve policymakers' understandings of the interconnections of science, technology, and economic policy and their importance for the American economy and its international competitiveness. One important element of STEP's analysis concerns the growth and impact of foreign technology programs. US competitors have launched substantial programs to support new technologies, small firm development, and consortia among large and small firms to strengthen national and regional positions in strategic sectors. Many state and local governments and regional entities are undertaking a variety of initiatives to enhance local economic development and employment through investment programs designed to attract knowledge-based industries and grow innovation clusters. STEP's project on state and regional innovation initiatives is intended to generate a better understanding of the challenges associated with the transition of research into products, the practices associated with successful state and regional programs, and their interaction with federal programs and private initiatives. The study seeks to achieve this goal through a series of complementary assessments of state, regional, and federal initiatives; analyses of specific industries and technologies from the perspective of crafting supportive public policy at all three levels; and outreach to multiple stakeholders.

NAE member **Mary L. Good**, Dean Emerita, Special Advisor to the Chancellor for Economic Development, University of Arkansas at Little Rock, and Former Under Secretary for Technology, US Department of Commerce, chaired the study committee. Paper, $46.00.

Energy Reduction at US Air Force Facilities Using Industrial Processes: A Workshop Summary. The Department of Defense (DOD) is the largest consumer of energy in the federal government, and the US Air Force is the largest consumer of energy in the DOD, with a total annual energy expenditure of around $10 billion. Approximately 84 percent of Air Force energy use involves liquid fuel consumed in aviation and about 12 percent is energy (primarily electricity) used in facilities on the ground. This workshop focused on opportunities to reduce energy consumption at Air Force facilities that use energy-intensive industrial processes (e.g., maintenance depots and testing facilities). In response to a request from the Air Force, a committee of the NRC's Air Force Studies Board held a workshop to discuss the following questions: (1) What are the current industrial processes that are least efficient and most cost ineffective? (2) What are best practices in comparable facilities for comparable processes to achieve energy efficiency? (3) What are the potential applications for the best practices to be found in comparable facilities for comparable processes to achieve energy efficiency? (4) What constraints and considerations might limit applicability to Air Force facilities and processes over the next 10 years? (5) What are the costs and paybacks from implementation of the best practices? (6) What will be proposed priorities for study and implementation of the identified best practices? (7) What does a holistic representation of energy and water consumption look like within operations and maintenance?

NAE members on the study committee were **Thom J. Hodgson**, Distinguished University Professor, Fitts Industrial and Systems Engineering Department, North Carolina State University, and **Carroll N. LeTellier**, retired vice president, Jacobs Engineering/Sverdrup. Paper, $39.00.

Underground Engineering for Sustainable Urban Development. As human activities begin to change the planet and populations struggle to maintain satisfactory standards of living, the placement of new infrastructure and related facilities underground may be the most successful way to encourage or support sustainable urban development. But much remains to be learned about improving the sustainability of underground infrastructure. At the request of the National Science Foundation, the NRC conducted a study to consider sustainable underground development in the urban environment, to identify research needed to maximize opportunities for using underground space, and to enhance understanding among the public and technical communities of the role of underground engineering in urban sustainability. This report explains the findings of researchers and practitioners with expertise in geotechnical engineering, underground design and construction, trenchless technologies, risk assessment, visualization techniques for geotechnical applications, sustainable infrastructure development, life cycle assessment, infrastructure policy and planning, and fire prevention, safety, and ventilation in the underground.

NAE members on the study committee were **Paul H. Gilbert** (chair), director emeritus, Parsons Brinckerhoff Inc.; **Chris T. Hendrickson**, Duquesne Light University Professor, Departments of Civil & Environmental Engineering and of Engineering & Public Policy, Carnegie Mellon University; and **George J. Tamaro**, consultant, Mueser Rutledge Consulting Engineers. Paper, $59.00.

Nuclear Physics: Exploring the Heart of the Matter. This report provides a long-term assessment of nuclear physics, articulating the scientific rationale and objectives of the field, providing a global context for the field and its long-term priorities, and proposing a framework for progress through 2020 and beyond. The committee carefully considered the balance between universities and government facilities in terms of research and workforce development and the role of international collaborations in leveraging future investments. Nuclear physics encompasses research that spans dimensions from a tiny fraction of the volume of the individual particles (neutrons and protons) in the atomic nucleus to the enormous scales of astrophysical objects in the cosmos. This report explains the research objectives, which include the desire not only to better understand the nature of matter interacting at the nuclear level but also to describe the state of the universe that existed at the big bang.

NAE member **Cherry A. Murray**, dean, School of Engineering and Applied Sciences, Harvard University, was a member of the study committee. Paper, $52.00.

Zero-Sustainment Aircraft for the US Air Force: A Workshop Summary. Air Force weapon system sustainment (WSS) costs are growing at more than 4 percent per year, while budgets have remained essentially flat. The cost growth is due partly to aging of the aircraft fleet and partly to the cost of supporting higher-performance aircraft and the new capabilities of more complex and sophisticated systems, such as the latest intelligence, surveillance, and reconnaissance platforms. Furthermore, sustainment budgets are likely to decrease, so that the gap between budgets and sustainment needs will likely grow wider. The original intent of this 3-day workshop was to focus on ways that science and technology (S&T) could help the Air Force reduce sustainment costs. However, as the workshop evolved, discussions focused increasingly on Air Force leadership, management authority, and culture as the more critical factors that need to change in order to solve sustainment problems. Many participants felt that while S&T investments could certainly help—particularly if applied in the early stages of the product life cycle—it would be more useful to adopt a transformational management approach that defines the user-driven goals of the enterprise, empowers people to achieve them, and holds them accountable, down to the shop level.

NAE members on the study committee were **Thom J. Hodgson**, Distinguished University Professor, Fitts Industrial and Systems Engineering Department, North Carolina State University, and **Lyle H. Schwartz**, senior research associate, Department of Materials Science and Engineering, University of Maryland, College Park, and retired director, Air Force Office of Scientific Research. Paper, $32.00.

Transitions to Alternative Vehicles and Fuels. For a century, almost all light-duty vehicles (LDVs) have been powered by internal combustion engines operating on petroleum fuels. Now energy security concerns over petroleum imports and the effect of greenhouse gas (GHG) emissions on global climate are driving interest in alternatives. This report assesses the potential for reducing petroleum consumption and GHG emissions by 80 percent across the US LDV fleet by 2050, relative to 2005. It examines the current capability and estimated future performance and costs for each vehicle type as well as non-petroleum-based fuel technology as options that could significantly contribute to these goals. The report also identifies barriers to implementation of these technologies and suggests policies to achieve the desired reductions. Approaches such as research and development, subsidies, energy taxes, or regulations will be necessary to overcome barriers such as cost and consumer choice.

NAE members on the study committee were **Douglas M. Chapin** (chair), principal, MPR Associates Inc.; **Gary L. Cowger**, retired group vice president, manufacturing and labor, General Motors Corporation; **L. Louis Hegedus**, retired senior vice president, research and development, Arkema Inc.; **John B. Heywood**, professor of mechanical engineering, Massachusetts Institute of Technology; and **Robert F. Sawyer**, Class of 1935 Professor of Energy Emeritus, Department of Mechanical Engineering, University of California, Berkeley. Paper, $59.00.

Assessment of Advanced Solid State Lighting. The standard incandescent light bulb, which still works mainly as Thomas Edison invented it, converts more than 90 percent of the consumed electricity into heat. With newer lighting technologies that convert a greater percentage of electricity into useful light, there is potential to decrease the amount of energy used for lighting in both commercial and residential applications. Although technologies such as compact fluorescent lamps will help increase energy efficiency, solid-state lighting (SSL) stands to help dramatically decrease US energy consumption for lighting. This report summarizes the current status of SSL technologies and products—light-emitting diodes (LEDs) and organic LEDs—and evaluates barriers to their improved cost and performance. It also discusses factors involved in achieving widespread deployment and consumer acceptance of SSL products, such as the perceived quality of light emitted by SSL devices, ease of use and the useful lifetime of these devices, initial high cost, and possible benefits of reduced energy consumption.

NAE members on the study committee were **John G. Kassakian** (chair), professor of electrical engineering and computer science, Massachusetts Institute of Technology; **Steven P. DenBaars**, professor and codirector of the Solid-State Lighting Center, Materials Department, University of California, Santa Barbara; **Michael Ettenberg**, Dolce Technologies; **Stephen R. Forrest**, vice president for research and professor, Departments of Electrical Engineering & Computer Science, Physics, and Materials Science & Engineering, University of Michigan; **Evelyn L. Hu**, professor, School of Engineering and Applied Sciences, Harvard University; and **Maxine L. Savitz**, retired general manager, Technology/Partnerships, Honeywell Inc. Paper, $45.00.

2011–2012 Assessment of the Army Research Laboratory. The NRC Army Research Laboratory Technical Assessment Board (ARLTAB) provides biennial assessments of the scientific and technical quality of the research, development, and analysis programs at the Army Research Laboratory (ARL). For 2011–2012, ARL asked the board to examine crosscutting work in the areas of autonomous systems and network science. The assessment showed that ARL staff demonstrate clear, passionate mindfulness of the importance of transitioning technology to support immediate and longer-term Army needs. In general, ARL is working very well in an appropriate research and development niche and has been demonstrating significant accomplishments.

NAE members on the study committee were **Lyle H. Schwartz** (chair), senior research associate, Department of Materials Science and Engineering, University of Maryland, College Park, and retired director, Air Force Office of Scientific Research; **David E. Crow**, retired senior vice president of engineering, Pratt and Whitney Aircraft Engine Company, and professor of mechanical engineering, University of Connecticut; **Debasis Mitra**, retired vice president, Chief Scientist's Office, Bell Labs, Alcatel-Lucent, and professor of electrical engineering, Columbia University; and **R. Byron Pipes**, John L. Bray Distinguished Professor of Engineering, Schools of Aeronautics and Astronautics, Chemical Engineering and Materials Engineering, Purdue University. Paper, $43.00.

Interim Report for the Triennial Review of the National Nanotechnology Initiative, Phase II. The National Nanotechnology Initiative (NNI) was established in 2001 as the US government interagency program for coordinating nanotechnology research and development and facilitating communication and collaborative activities in nanoscale science, engineering, and technology across the federal government. The NRC's third triennial review of the NNI concerned three areas: Task 1—Examine the role of the NNI in maximizing opportunities to transfer selected technologies to the private sector, assess how well the NNI is carrying out this role, and suggest new mechanisms to foster transfer of technologies and improvements to NNI operations in this area where warranted. Task 2—Assess the suitability of current procedures and criteria for determining progress toward NNI goals, suggest definitions of success and associated metrics, and provide advice on organizations (government or nongovernment) that could perform evaluations of progress. Task 3—Review NNI's management and coordination of nanotechnology research across both civilian and military federal agencies. This interim report offers initial comments on the procedures and criteria for determining progress toward and achievement of the desired outcomes.

NAE members on the study committee were **Ilesanmi Adesida**, vice chancellor for academic affairs and provost, University of Illinois at Urbana-Champaign; **Paul A. Fleury**, Frederick William Beinecke Professor of Engineering and Applied Physics/professor of physics, Yale University; **Elsa Reichmanis**, professor, Department of Chemical and Biomolecular Engineering, Georgia Institute of Technology; and **Charles F. Zukoski**, provost, State University of New York at Buffalo. Paper, $29.00.

Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites. Across the United States, thousands of hazardous waste sites are contaminated with chemicals that prevent the underlying groundwater from meeting drinking water standards. These include Superfund sites and other facilities that handle and dispose of hazardous waste, active and inactive dry cleaners, and leaking underground storage tanks; many are at federal facilities such as military installations. This report estimates that at least 126,000 sites still have contaminated groundwater, and their closure is expected to cost as much as $127 billion. About 10 percent of these sites are considered "complex," meaning restoration is unlikely to be achieved in the next 50 to 100 years because of technological limitations. At sites where contaminant concentrations have plateaued at levels above cleanup goals despite active efforts, the report recommends evaluating whether they should transition to long-term management, where risks would be monitored and harmful exposures prevented, but at reduced costs.

NAE members on the study committee were **Jerome B. Gilbert**, consulting engineer, Orinda, California, and **Michael C. Kavanaugh**, principal, Geosyntec Consultants. Hardcover, $49.00.

Optics and Photonics: Essential Technologies for Our Nation. Optics and photonics technologies are ubiquitous: they are responsible for the displays on smart phones and computing devices, optical fiber that carries information in the Internet, advanced precision manufacturing, enhanced defense capabilities, and a host of medical diagnostics tools. And they offer the potential for even greater societal impact in the next few decades, including solar power generation and efficient lighting that could transform the nation's energy landscape, and new optical capabilities that will be essential to support the continued exponential growth of the Internet. This report assesses the current state of optical science and engineering in the United States and abroad in terms of market trends, workforce needs, and the impact of photonics on the national economy. It identifies technological opportunities that have arisen from recent advances in and applications of optical science and engineering. The report also calls for improved management of US public and private research and development resources, emphasizing the need for public policy that encourages a portfolio approach to investing in the opportunities available in photonics.

NAE members on the study committee were **Rod C. Alferness**, retired chief scientist, Alcatel-Lucent, and Richard A. Auhll Professor and dean, University of California, Santa Barbara; **David A.B. Miller**, W.M. Keck Foundation Professor of Electrical Engineering, Stanford University; **Duncan T. Moore**, vice provost for entrepreneurship and Rudolf and Hilda Kingslake Professor of Optical Engineering, Institute of Optics; and **Edward I. Moses**, principal associate director, Lawrence Livermore National Laboratory. Paper, $65.00.

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