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PRECOLLEGE STEM EDUCATION

The

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LINKING ENGINEERING AND SOCIETY

On the Road to Reform: K–12 Science Education in the United States

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American Science Education in Its Global and Historical Contexts

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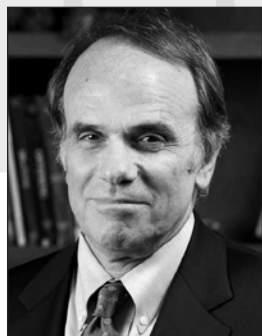
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Editor's Note



Michael J. Feuer is Dean and professor of education policy at the Graduate School of Education and Human Development, The George Washington University.*

STEM Education: Progress and Prospects

Historians of American education will note the significance of the timing of this issue of *The Bridge*—almost exactly 30 years after the publication of what is considered among the most influential education policy documents of the 20th century. The rhetoric of *A Nation at Risk: The Imperative for Educational Reform* (NCEE 1983) captivated the public and professional worlds of schooling and played a major part in the ensuing drama of standards, assessment, and accountability that have become the pillars of reform.

A core argument in *Nation at Risk* centered on the convergence of two intuitively compelling assumptions. First, America's place in the world, in terms of productivity, competitiveness, and other economic determinants of quality of life, hinges to a large extent on the strength of the scientific and technological workforce. US investments in research and development—both physical infrastructure and, even more importantly, human capital—have yielded stunning social and economic returns. There is overwhelming evidence that

the American experiment in mass public education, coupled with increased public and private investment in technological innovation, was largely responsible for the unparalleled success of the US economy through much of the 20th century (see, e.g., Atkinson and Pelfrey 2010; Goldin and Katz 2008).

Second, among the most important ingredients of America's long-term stature, especially in an era of global technological change, is the quality of US education in science, technology, engineering, and mathematics (STEM), starting in the early grades and extending well beyond the traditional postsecondary years. On this point, too, there is little debate: precollege experiences of this country's increasingly diverse student body, in general and specifically in the STEM fields, are the foundation for their capacity as productive, innovative, and technologically competitive citizens. How well US colleges and universities and workplaces will be able to maintain and grow their research and development capacity depends, to a great degree, on the sustained flow of prepared youth.

If the rhetoric of *Nation at Risk* was gripping—who can forget the unfiltered warning that “if an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war”—the connections between diagnosis and prescription were, and remain, logically and empirically challenging. Consider the implicit proposition that economic competitiveness is principally a function of academic achievement, as measured mostly by test scores. From the earliest days of US involvement in international comparisons of student achievement, the United States has fared poorly (see, e.g., Medrich and Griffith 1992): in the First International Mathematics Study (FIMS) in 1964, the United States ranked at the bottom among 12 countries in the test performance of 13-year-olds and of students in the last year of secondary school. (The “golden age” romanticism of some policy pundits, who like to argue that America was once number one in the world but is no longer, is obviously put to the test by these early results; see also Feuer 2012; Loveless 2011.) Assuming these students entered the labor force some time in the following decade and assuming that their academic achievement was a significant determinant of their

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subsequent productivity, one would have expected to see, during the 1970s and beyond, substantial differences in aggregate economic performance between the United States and the other countries that participated in FIMS.

It is true that in the mid-1970s the United States experienced a temporary annual decline in productivity growth (an essential indicator of broad economic trends), from an average of 2.5 percent in the 1960s to 1.9 percent in the next decade (Baumol et al. 1989; Feuer 2012; Williamson 1991). In itself, this would seem to indicate a causal link between low test scores and sluggish economic performance. But the data are more complex. In that period—comparing the 1960s to the 1970s—the countries that outperformed the United States on FIMS experienced similar *or worse* declines in average annual productivity than the United States. England, for example, ranked second on FIMS in mathematics for students in their final year of secondary school but saw its average annual productivity growth rate drop from 3.56 in the 1960s to 2.77 in the 1970s.

An even more startling comparison is between the United States and Japan: for the latter, which ranked 6th in FIMS, average productivity growth plummeted from 9.96 percent per annum in the 1960s to 5.03 percent in the 1970s (Baumol et al. 1989; Williamson 1991), an almost 50 percent decrease, compared with the US decline of about 30 percent. All else equal, the temptation to attribute national economic stagnation (or growth) to mean academic performance on standardized achievement tests would have led to the conclusion that American education was, in fact, superior to Japanese education.

Obviously, neither the dismal news about US ranking on FIMS nor the uplifting news about US economic resiliency compared to other countries would be valid without a host of caveats. Problems associated with sampling, population participation, and linguistic barriers to test item development and scores (see Medrich and Griffith 1992), especially in the early years of large-scale international comparative work, should have tempered the gloomier rhetoric. But progress in the design and interpretation of comparative assessments has made them an essential part of education policy analysis. And even if the tendency to lurch toward policy prescriptions somewhat prematurely, based on data that require more nuanced interpretation, is a fact of political life, that should not dissuade investment in and careful study of cross-national data—especially those relevant

to STEM education at all levels (see also Engel et al. 2012; Feuer 2013).

In the current political environment, the condition of STEM education and its relationships to broad educational and economic trends retain a central and legitimate place in the policy agenda, and are the subjects of the articles prepared for this issue.

We begin with a basic question: To what extent do data support the hypothesis that either US science and engineering capacity has declined or, given current conditions of precollege science and mathematics instruction, such a decline is inevitable? Embedded in this question are familiar tropes from recent reports and headline news; the influential National Academies report *Rising Above the Gathering Storm* (NAS/NAE/IOM 2007, p. x), for example, noted that some 40 percent of scientists reported to Congress that American science was “in a stall” and 60 percent asserted it was already “in decline.”

But both the underlying data upon which the National Academies diagnosis was based and the ensuing policy recommendation—to vastly increase the quantity of young people prepared for and entering postsecondary STEM—have been subject to debate. The first two papers in this issue address the following questions: What is known about the condition of precollege STEM education in the United States compared to our global competitors? What are the effects of the American penchant for a diffused and perhaps inchoate science and mathematics curriculum, as compared to countries with tighter control over the scope and substance of curricula? How valid is the assertion that American science and engineering are in decline? To what extent do the data support anxieties about the “leaky pipeline”—the notion that many young people who express interest in and begin studying STEM subjects switch out during their academic career? And to what extent does such a drop-off portend significant losses in terms of unmet supply of talent for the global and technologically changing economy?

The opening paper presents an eloquent overview of seminal empirical work associated with William Schmidt and colleagues, who have for decades been studying US science and mathematics performance at the K–12 level, with emphasis on comparisons drawn from large-scale international assessments and in-depth curriculum and teaching studies. The authors present compelling arguments for their hypothesis that the US “mile-wide-but-inch-deep” approach to science

education is a major cause of this country's relatively low performance on international tests. The second paper, by Sasha Killewald and Yu Xie, expands some of the issues raised in their recent book, *Is American Science in Decline?* (Xie and Killewald 2012), and calls for a balanced prognosis based on analysis of multiple data sources.

We then move to a question that is sometimes ignored or underemphasized in the debate on the condition of STEM education in America. Suppose for argument's sake that available indicators suggested that US STEM education was in reasonably good shape and that, from the standpoint of national economic need, the supply of talent was not at risk. Note that I am not advocating quite this degree of optimism or complacency; my point, rather, is to direct attention to the need for disaggregation: *To what extent are minorities and women adequately and equitably represented in the nation's STEM enterprise?* Does evidence of underrepresentation pose problems of equity in the distribution of opportunity and efficiency in fulfilling the country's future STEM needs? In other words, does the imperative to correct inequalities in the US education system, a goal worthy in its own right, converge with the need to fulfill increased demand for scientists and engineers to maintain America's competitive edge in the global economy?

Two papers address these issues. The first, by Lindsey Malcom-Piqueux and Shirley Malcom, focuses on *institutional* mechanisms to improve STEM education for women and underrepresented minorities. Building on data and assumptions about precollege preparedness, the authors identify promising programmatic options for colleges and universities to consider as they attempt to raise the proportion of minority and female students entering into and persisting in STEM majors. The second article, by Liliana Garces and Lorelle Espinosa, addresses a key aspect of the *policy* environment: the effects of *law* and changing jurisprudence on programs designed to increase opportunities for women and underrepresented minorities. Both papers establish a strong basis for understanding—and shaping—the link between K–12 and postsecondary STEM education.

One of the historically persistent challenges of education policy has been to reconcile compelling arguments for a *national* ethos about schools and schooling with America's deep-seated cultural and political allergy to centralized authority (see, e.g., Cremin 1990; Feuer 2006; Vinovskis 1999). Against this backdrop, the achievement of the “Common Core State Standards”

is all the more stunning. This project, originating in the states (with federal government and private sector blessing), represents the latest attempt to solve the fundamental “*e pluribus unum*” problem in American education. It began in 2009 with the goal of designing standards in mathematics and in English/language arts, has been voluntarily adopted by 45 states and the District of Columbia, and has now been extended to science and engineering education thanks to the work of the NRC's Board on Science Education.

With support from several enlightened philanthropies and the National Academies, the Board developed a “framework” that is now being used as the foundation for the crafting of the Next Generation Science Standards—coming almost 20 years after the pioneering NRC Science Standards (NRC 1996)—for K–12 science education. The article by Heidi Schweingruber and her colleagues chronicles the procedural and substantive challenges—and successes—of this initiative. Experts will debate the pros and cons of the standards movement generally and of science frameworks/standards specifically; but there is no question in my mind that the caliber and expertise of those involved and their consummate devotion to the cause of improving STEM education for all US students at all levels should be a source of great optimism.

Our main goal in this issue is not to “solve” the problems of STEM education. That would exceed the bounds of our rationality (and humility). Rather, we hope to stimulate an ongoing dialogue, based on and guided by careful analysis of data, among policymakers and institutional leaders working on reform. If we have raised questions here about the quality of existing data, the need for more and better data, and priority topics for a sustained research agenda, so much the better. I am immensely grateful to Ron Latanision for his wise decision to focus this (and the next) issue of *The Bridge* on education, and to Cameron Fletcher for superb editorial guidance. The authors of these papers and I hope that our efforts will be appreciated—and debated—by readers of *The Bridge*, and we very much look forward to the conversation as it unfolds.

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If there is to be a next generation of great US scientists and engineers, the system of science education must inspire students' interest in STEM and help them reach their potential.

On the Road to Reform

K–12 Science Education in the United States

William H. Schmidt, Nathan A. Burroughs,
and Leland S. Cogan



William H. Schmidt



Nathan A. Burroughs



Leland S. Cogan

America has grown accustomed to being a leader in technological innovation, thanks in large part to its human capital (see, e.g., Goldin and Katz 2008). Historically, American workers have been among the best educated and most skilled in the world, and the scientists and engineers employed by US businesses and universities (whether they were born here or abroad) have been at the forefront in scientific discovery.

But this advantage cannot be taken for granted. Not for the first time, concerns are being raised about whether the US educational system is continuing this tradition. At the height of the Cold War, fears aroused in the wake of the Soviet Union's Sputnik launch inspired a massive investment

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of public resources in improving the training of US scientists and engineers. In today's more multipolar world, American institutions and workers are in fierce competition with the previously untapped talents of other nations. Confronted with these challenges, the question is whether the American educational system is preparing US students in the science, technology, engineering, and mathematics (STEM) fields well enough to preserve the US advantage over other countries that are trying to catch up.

The challenge is twofold. If there is to be a next generation of great US scientists and engineers, the system of science education must inspire students' interest in STEM and help them reach their potential. The United States cannot count on being able to import the brightest minds of other countries forever. At the same time, US schools have to cultivate scientific literacy and habits of scientific thinking among all students. Americans need to feel comfortable with incorporating scientific concepts in their daily lives for economic reasons, given the growing role of technology in the workplace but also because issues related to science have moved to the center of the nation's public debate. Discussions about the environment, public health, economic growth, energy, even subjects that are conventionally considered "social" issues are all infused with scientific content. It's hard to imagine a nation remaining a world leader in science over the long term without a citizenry well informed about science.

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US Performance in Science Education

Unfortunately there is a large body of evidence indicating that US students are not learning as much about science as their peers in other countries. Any relative advantage that they enjoyed during the 20th century has disappeared. Even if concerns were limited to the output of scientists and engineers by American

universities, there would still be reason to worry. According to a report by the US Congress Joint Economic Committee (2012), although the United States produces more STEM graduates than other industrialized (OECD) nations in terms of raw numbers (no great feat given its much larger population), it ranks 23rd in the percentage of 25- to 34-year-old workers who have a STEM degree.

Demographics among Advanced Degrees

Interest in STEM among postsecondary students appears to be on the wane: whereas in 1985 18 percent of master's degrees and 24 percent of bachelor's degrees were in STEM fields, by 2006 those numbers had declined to 14 percent and 18 percent, respectively. The fact that the share of STEM PhDs has remained steady should provide no comfort, as the proportion of *American-born* STEM PhDs dropped from three-quarters (74 percent) to just over half (54 percent) over a 20-year period. Part of this decline is due to the underrepresentation of disadvantaged minorities among STEM graduates—groups that make up an ever greater share of the US population (Burroughs 2012; also see articles in this issue by Garces and Espinosa and by Malcom-Piqueux and Malcom). Although there is debate about whether there is currently a shortage of STEM graduates (complicated by the unclear effects of the weak economy), the much larger percentage of foreign-born college graduates in STEM than in other fields (Gambino and Gryn 2011; Siebens and Ryan 2012) suggests problems in the US K–12 educational system. This is a particular problem in engineering, where a *third* of all of those with a bachelor's or more are nonnative born, twice their share of the US population.

Tests of K–12 Performance

The scientific knowledge of American students starts out fairly strong in early grades relative to children in other countries, but this advantage steadily erodes as they progress. This problem is demonstrated by two assessments of scientific knowledge: the science portions of the US National Assessment of Educational Progress (NAEP)¹ and the Trends in International Mathematics and Science Study (TIMSS). The 2009 NAEP indicates that just over a third (34 percent) of US 4th graders are proficient in science, 30 percent in 8th grade, and only

¹ Data collected from the NAEP data explorer, <http://nces.ed.gov/nationsreportcard/naepdata/>.

21 percent in 12th grade. In addition, only a vanishingly small 1–2 percent of US students demonstrated an advanced knowledge of science. Although the science NAEP does not at present permit the calculation of long-term trends, a more recent version of the 8th grade NAEP test showed similar results, with a slightly higher 32 percent proficiency.

The 2007 TIMSS² also makes the point: in 4th grade US students on average scored 539 on the test (ranking 8th among the countries tested), compared with an international average of 500. By 8th grade, they averaged only 520 and were ranked 11th. Since 1995, 4th grade scores have slightly declined (by 3 points) and in 8th grade increased marginally (7 points), although neither of these trends is statistically significant. The US ranking has declined since 1995 for 4th graders, falling from 2nd place, and risen slightly (from 12th) for 8th graders. The TIMSS has a different threshold for its “advanced” level, with 15 percent of 4th graders and 10 percent of 8th graders, numbers that are greater than the international median but that have both declined since 1995 (Gonzales et al. 2009).

The emphasis of the other major international assessment, the Program for International Student Assessment (PISA), is different from that of the TIMSS or NAEP, focusing on the practical application of concepts rather than formal knowledge. The PISA also tests a larger number of countries (both OECD and non-OECD), giving a fuller picture of a country’s relative educational performance. It is noteworthy then that the US performance in science on the 2009 PISA was decidedly mediocre: just 502, compared with the average OECD score of 501 (out of about 800). The United States ranked 17th among 33 OECD countries and 23rd among the 64 participating countries. US performance on the PISA has trended upward since 2006 (up from 489), but its relative ranking did not improve: from a comparative perspective, American students are running in place (Fleischman et al. 2010).

The deteriorating relative position of US students as they proceed through school appears to continue in high school. The 1995 TIMSS³ indicated that by the

end of secondary school US students had fallen to 16th of 21 countries in science literacy and well below the international average in physics content areas (Mullis et al. 1998).

Although not our focus here, problematic US mathematics education also impedes the development of a STEM-literate population. As in science, there is a host of evidence from national and international sources that US students are inadequately prepared in mathematics (Schmidt 2012). Only a third of US 4th graders and a quarter of 8th graders reached the level of proficiency on the NAEP; on the TIMSS US students received middling scores, and they did quite poorly on the PISA.

From a comparative perspective, American students are running in place.

Inequalities in Opportunity to Learn

One of the main obstacles to US science achievement (as with the output of STEM graduates) is the persistence of achievement gaps. All three assessments of US students (PISA, TIMSS, and the NAEP) indicate that low-income and minority students trail their peers by a full standard deviation or more—greater than the half a standard deviation difference between the United States and Singapore on the PISA. Indeed, as laid out in the recent book *Inequality for All* (Schmidt and McKnight 2012), the US educational system is characterized by pervasive inequalities in opportunity to learn, and such opportunities are strongly related to actual learning (Schmidt and Maier 2009). Students attending low-income schools, whatever their ethnicity, face a particular burden, scoring a full standard deviation and a half below students in affluent schools. In failing to provide educational opportunities to all of its students, the United States is essentially wasting the talents of millions of schoolchildren.

Barriers to Achievement in Science: The Role of Curriculum

After decades in which educational reform policies concentrated on the amount and distribution of educational resources and the structural features of American

² These are the most recent data available as the TIMSS is conducted every 5 years.

³ TIMSS conducted a study of secondary school students only in 1995, but given the stable performance of US students at other grades and in other assessments, these results very likely hold true in 2013.

education, policymakers are now placing an increasing emphasis on the role of instructional content. This new focus is appropriate: what a child has a chance to learn is largely a product of the content to which the student is exposed in the classroom. Although other factors such as socioeconomic background are also important, opportunity to learn has a significant impact on student outcomes—an impact that is the direct result of educational policy. Unlike other nations, the United States has long stood outside the mainstream in its treatment of curriculum, leaving decisions about what students have an opportunity to learn up to state governments or school districts. Unfortunately this has led to a fragmented curriculum and a patchwork of different educational standards, with a dramatic impact on the overall quality of instruction in math and science.

Research shows that there are three main features of a strong STEM curriculum: focus, rigor, and coherence.

The Need for Focus, Rigor, and Coherence in Curriculum

International research as part of the TIMSS reveals three main features of a strong STEM curriculum: focus, rigor, and coherence (Schmidt et al. 2005). A focused curriculum concentrates on a few key topics at a time, aiming for student mastery. A rigorous curriculum introduces students to these topics at a demanding yet developmentally appropriate level. A coherent curriculum organizes topics in a logical way, moving from the simple to the complex.

Developing a coherent curriculum in mathematics is a much more straightforward task than it is for science. Mathematics is fundamentally a hierarchical discipline, with its own logical structure naturally placing some concepts (e.g., basic arithmetic algorithms) before others (e.g., linear equations and functions). Science, however, is less a single distinct subject than an entire family of content—related to one another, to be sure, but each with its own specific character.

The US science curriculum is “a mile wide and an inch deep,” covering a large number of topics in a scattershot, shallow fashion rather than systematically and

in depth. These features are evident both in state and district standards and in textbooks (another important influence on the curriculum). The US science curriculum stands in stark contrast to that of other nations, in particular high-achieving ones such as Japan. Of 79 basic scientific content topics that constitute the TIMSS science framework (Schmidt et al. 1997), US students generally cover more than students in other countries, coverage that tends to be repeated across grade levels without appreciably deepening their knowledge or understanding.

A key question in science is at what grade level a given subject enters the curriculum, since, once included, it tends to remain a part of the curriculum, with a limited increase in depth over time. An examination of the common characteristics of the nations that did best in science on the 1995 TIMSS indicated that higher-performing, or “A+,” countries usually covered little science in grades 1 and 2 (Schmidt et al. 2005). The later primary grades presented basic scientific concepts such as the classification of living organisms, the earth’s features, the nature of matter, and different kinds of energy—topics that serve as the bedrock for physics, biology, and earth science. In early middle school biology topics such as the classification of living organisms and morphology as well as the structure of the solar system and the concept of gravity are introduced. By 7th and 8th grade more advanced topics in chemistry and physics receive attention. In each subfield there is a clear progression from simple description and classification to explanations of change and the underlying processes that govern the physical world.

By comparison, US state standards generally aim to cover many more topics and to do so in every grade, as well as beginning science coverage in the early grades, when they are frequently little more than lists of vocabulary words. An analysis of 44 state standards in 2000 revealed almost no agreement in content coverage across states, and as many as 50 topics to be covered at each grade—far too many for adequate instruction (Schmidt and McKnight 2012). Moreover, a selection of school district standards showed only modest agreement with international benchmarks (39 percent), great variation in content rigor, and little focus.

Textbooks

US science textbooks tend to replicate many of the same flaws as standards, being by international standards very long, very unfocused, and far too elementary.

US texts in 4th and 8th grade average 50–65 discrete scientific topics, compared with 5–15 in Japan and 7 in Germany (Cogan and Schmidt 1999; Schmidt et al. 1997). Even textbooks that purport to cover a specific domain of science (e.g., physics) tend to include a large number of topics from other fields. US elementary and middle school textbooks indicate a bias in favor of biology over chemistry and physics, but there is a considerable range in the emphasis given to topics in each of these broader categories.

A further problem in US textbooks is interrupted coverage, as topics are temporarily dropped and later resumed. For example, in 8th grade, US textbooks had between 300 and 600 breaks in topic coverage. The international mean was 88 (Schmidt and McKnight 2012).

Finally, only 20 percent of US 8th grade textbook content involved more complicated information as opposed to simple topics. The typical textbook in other countries devotes about 40 percent of its material to more advanced topics. The danger in a more simplistic approach to science education is that students learn lists of vocabulary words rather than internalizing the scientific approach and learning how to apply it to the world.

Teacher Preparation

Standards and textbooks are examples of the *intended* curriculum (what students are expected to learn). It is just as important to examine the quality of the *implemented* curriculum, the content that is actually offered to students in classroom. The key intermediary between intended and implemented curriculum is the science teacher, who has the biggest impact on the content of science instruction. Unfortunately many teachers are not adequately prepared to teach science.

The results of the NCES Schools and Staffing Survey⁴ indicate that, although 76 percent of high school biology teachers have a major or minor in biology, much smaller proportions of teachers of chemistry (25 percent), earth science (33 percent), physical science (49 percent), or physics (58 percent) have the same level of training. These results are quite similar to those from a survey of teachers in 60 school districts as part of the NSF-funded Promoting Rigorous Outcomes in Mathematics and Science Education (PROMSE) project. That study also surveyed middle school teach-

ers and concluded that those without field-specific training were much less comfortable teaching science topics and that, while 80 percent of high school science teachers had a major or minor in science, only 41 percent of middle school teachers have training in a scientific field. It is hard to expect teachers to implement a strong science curriculum if they are insufficiently prepared.

Adding It All Up

The very problematic quality of teacher preparation, standards, and textbooks contributes to the uneven quality of science instruction, measured according to the choice of topic covered, how many grades, or the time spent on it in a given grade. Studies examining the content of instruction indicate that US topic coverage is far more diffused than in other countries, such as Japan (Schmidt et al. 1999). Even within scientific disciplines, there is very little concentration in the time dedicated to any particular group of topics (Cogan and Schmidt 1999; Schmidt et al. 1997). And again, there is massive variation across school districts and classrooms in the emphasis on given topics. In comparison with the importance placed on physics and chemistry in other nations, in some US classrooms nearly half of the time allocated to science teaching is devoted to these topics and in others they are entirely absent. The difference in the time spent on biology, physics, and chemistry in a given year can range from two to four weeks across classrooms (i.e., class time may be 1 week at one school, 5 weeks at another, and 3 at another).

Science teachers have the biggest impact on the content of science instruction, but many are not adequately prepared to teach science.

In sum, the problem of inadequate STEM preparation is linked to the failure to create a coherent science curriculum. The fragmented, incoherent science curriculum—both intended and implemented—poses a potential solution to the puzzle of why American students in elementary and middle school demonstrate a

⁴ Available online at http://nces.ed.gov/surveys/sass/tables/sass0708_009_t1n.asp.

reasonable grasp of scientific knowledge, but have a limited ability to apply these concepts and evince little desire to pursue science as a career.

If scientific topics are littered across classrooms in an almost random fashion, if each scientific subfield is treated as an isolated unit unconnected to the rest, if science is simply a collection of facts offered by teachers who are not always comfortable with them, then can it be any surprise that so many American students fail to take an interest in science?

The “8+1” approach begins with inquiry (“+1”) and leads students through 8 fundamental concepts of science.

Improving Focus and Coherence in US Science Instruction

Focus and coherence have always been a challenge in science standards because, as mentioned above, science is not a single discipline. The latest generation of science standards crafted by the National Research Council (NRC 2012; also see Schweingruber et al. 2013 in this issue) made this explicit in its listing of the four disciplinary cores: physical sciences, life sciences, earth and space sciences, and engineering and technology. Note that each of these isn’t a single science but a group of scientific disciplines. The inclusion of numerous subfields to be covered in K–12 science education is likely to increase the already large number of topics and may complicate the effort to fashion a more focused curriculum. An examination of the focus and coherence exhibited in the standards of top achieving countries can provide some guidance, yet such an approach seems to yield little more than a pared down “shopping list” of topics in search of a coherent perspective. How, then, can focus and coherence be brought to the US K–12 science curriculum?

The 8+1 Approach

This was the perplexing challenge facing our NSF-funded project that sought to improve K–12 mathematics and science instruction and learning in over 60 school

districts. A group of scientists and science educators⁵ approached the challenge of focus and coherence by identifying a small number of key concepts that govern the natural world (Schmidt et al. 2011). The idea was that these concepts would cut across the science disciplines and limit the number of essential topics to create a more coherent framework for approaching the whole of science. The result was a set of principles or concepts the group dubbed the “8+1.” In the NRC’s *Framework for K–12 Science Education*, the “crosscutting concepts” are similarly conceived, in that they are intended to cut across the science disciplinary silos (NRC 2012; Schweingruber et al. 2013). The 8+1 approach attempts to move a step further by responding to three overarching questions:

1. How do we know what we know?
2. Of what are things made?
3. How do systems interact and change?

The answer to the first question, “inquiry,” is the “+1” in the 8+1. Responses to the other two questions about the natural world yield the 8 fundamental concepts of science. In this way the distinguishing feature of science as inquiry is viewed as the means by which one responds to the first overarching question and can formulate responses to the other two.

The following three concepts inform responses to the second question:

- Everything is made of atoms and atoms are composed of subatomic particles.
- Cells are the basic units of organisms.
- Electromagnetic radiation pervades the world.

Responses to the third question yield the final five concepts:

- Evolution: Systems evolve and change with time according to simple underlying rules or laws.
- Parts of a system move and interact with each other through forces.
- Parts of a system can exchange energy and matter when they interact.

⁵ The group members were Simon Billinge, Audrey Champagne, Richard Hake, Paula Heron, Leon Lederman, George Leroi, Lillian McDermott, Fred Myers, Roland Otto, Jay Pasachoff, Carl Pennypacker, William Schmidt, and Paul Williams.

- Physical concepts like energy and mass can be stored and transformed, but are never created or destroyed.
- Life systems evolve through variation.

These concepts⁶ were developed not as a new set of standards but as a set of fundamental principles that support and provide connection among the many different topics included in science standards. The goal in creating the 8+1 framework is to support whatever standards are the focus of classroom instruction as well as whatever textbooks or materials are in use, to go beyond the facts and connect them to the 8+1 fundamental concepts. In addition, the concept of *system* is an important idea that moves science instruction away from a consideration of isolated facts (and vocabulary) and instead emphasizes the dynamic relationships among system elements.

The vision is to have the 8+1 serve as the foundation that supports and informs instruction and the effort to help students make sense of the natural world. Coherence, then, emerges in the science curriculum not only through the sequence in which topics are covered but, more importantly, in the many connections that can be made explicit among them through the 8+1. These fundamental concepts are always relevant in that many (if not most) of them undergird whatever topic may be taught.

Cultivating the Next Generation of US Innovators

In creating a framework that helps students synthesize across scientific subfields, the 8+1 has the potential to foster greater science literacy. As understood by physicist and Nobel Laureate Leon Lederman, one of the authors of 8+1, students need to comprehend both what science is and what it is for. According to Lederman:

Science is able to explain the way the natural world works by means of a small number of laws of nature. These laws, often expressed mathematically, are explored using tools such as observation, measurement, and description. Information is synthesized into understanding through creative thought with predictions continuously tested by observation and measurement. (Schmidt et al. 2011, p. 7)

Engineering could play a useful role in realizing the 8+1. It is not a separate science discipline but rather

the application of scientific concepts and principles to solve specific problems. Structuring science instruction around the 8+1 provides a way to bring engineering into the classroom on a regular basis. Both the practice of engineering and the conceptual foundation of the 8+1 embrace the multidisciplinary nature of science and make explicit use of the interconnections. These linkages, brought together in a practical solution or linked to fundamental crosscutting concepts, can bring much-needed coherence to science instruction by making science a compelling reality for students.

The fundamental science concepts embodied in 8+1 are not a miracle cure for what ails science learning, but they do suggest a compelling approach to improved science instruction in the classroom that merits exploration. Assuming that a fragmented, mile-wide inch-deep science curriculum is a major contributor to mediocre science literacy and a lack of interest in STEM careers, the 8+1, together with improved preparation of teachers of science and an aggressive effort to reduce the inequality in opportunity to learn science, presents a promising strategy for fostering the next generation of American innovators.

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⁶For more information about the concepts and their age-appropriate definitions, see <http://8plus1science.org/>.

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Although American science education is facing increasing international competition, US science and economic growth can reap the benefits of globalization.

American Science Education in Its Global and Historical Contexts



Alexandra Killewald



Yu Xie

Alexandra Killewald and Yu Xie

In 2009, students in Shanghai topped their peers around the world in math, science, and reading scores on the Program for International Student Assessment (PISA), a test administered to 15-year-olds in 65 countries, while American schoolchildren placed near the middle of the group (OECD 2010). The release of the disappointing PISA results (and other international comparisons) has been a source of national angst and the stimulus for rapid policy response in many countries (see, e.g., Engel et al. 2012; Feuer 2012), and prompted a wave of alarm in the United States: Why did American children not fare better? What could be done to improve results? Secretary of Education Arne Duncan referred to the results as “a wake-up call” (Dillon 2010), and a *USA Today* (2010) headline announced, “In ranking, US students trail global leaders.”

Yet the relatively mediocre performance of American adolescents compared with their Asian peers on the 2009 PISA was not new. The 2007 Trends in

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International Mathematics and Science Study (TIMSS) showed similar results and met with a similar reaction (IEA 2008). Francis Eberle, executive director of the National Science Teachers Association, asked, “Do we want to be average?” (Toppo 2008). In 2008 Ina V.S. Mullis, codirector of the center that administers TIMSS, noted with concern the gap between the performance of American schoolchildren and children in the highest-performing Asian countries (Dillon 2008), and the 2010 issue of *Science and Engineering Indicators* reported that 70 percent of adult Americans said they were dissatisfied with the quality of math and science education in US schools (NSB 2010, Chapter 7, p. 7-42).

Many fear that, in an increasingly globalized world, the United States may not be improving fast enough to keep up.

The news coverage of these test results highlights that, for many Americans, performance in math and science is important both as a measure of ground gained relative to the performance of earlier cohorts of Americans and as an indicator of the United States’ ability to remain dominant in an increasingly competitive global landscape. In the words of Arne Duncan, “We live in a globally competitive knowledge based economy, and our children today are at a competitive disadvantage with children from other countries.... [T]hat puts our country’s long term economic prosperity absolutely at risk” (USA Today 2010). Many other policymakers, educators, and journalists have also raised the concern that, in an increasingly globalized world, the United States may not be improving fast enough to keep up. Thus concerns about the competitive position of American science education are related to fears for the economic future of the United States, particularly in comparison with China and other emerging Asian economies.

However, this pessimistic view is only one way of looking at the state of US science education (see also Feuer 2012). In this article, we present a more balanced view. We begin with a brief review of the relative per-

formance of American schoolchildren on international tests of achievement in science and mathematics. While our results in this area support the conclusion that US students perform about average on standardized tests, they also document gains compared to earlier cohorts of Americans, showing that US science and math education has improved over its past.

After looking at test scores as indicators of the quality of future American scientists, we shift our attention to quantity. We find no evidence that American college students are turning away from the pursuit of math and science majors. We also find that counterclaims of a surplus of US scientists are overblown. Finally, we present an alternative view of globalization and science, explaining the ways global scientific collaboration may benefit the United States even if America is no longer the top performer.

American Students’ Performance from a Global Perspective

To examine the performance of American schoolchildren in the international context, we use scores from the 2006 administration of PISA, in which 57 countries participated, and the 2007 administration of the 4th grade TIMSS, which involved 36 countries (Gonzales et al. 2009; OECD 2007).¹

In comparing countries’ educational outcomes, it is useful to consider test scores in the context of each country’s level of economic development (e.g., based on per capita GDP in the same year). If the United States is performing at mediocre levels despite considerable economic resources, the implication is that the government is either investing less than other countries’ governments in math and science education (at least as measured by these tests) or using its resources less effectively.

To measure economic resources across countries in comparable terms, we use Penn World Table Version 6.3, which adjusts for differences across countries in the goods and services that can be bought with one unit of currency (Heston et al. 2009). The results for 4th graders’ TIMSS scores in math and science are shown in Figure 1.² Each dot represents a country or place, with

¹ This section draws on the results of our analysis reported in Xie and Killewald (2012).

² Because of Kuwait’s very high GDP and poor test results, we excluded it from the dataset to avoid unduly influencing the results.

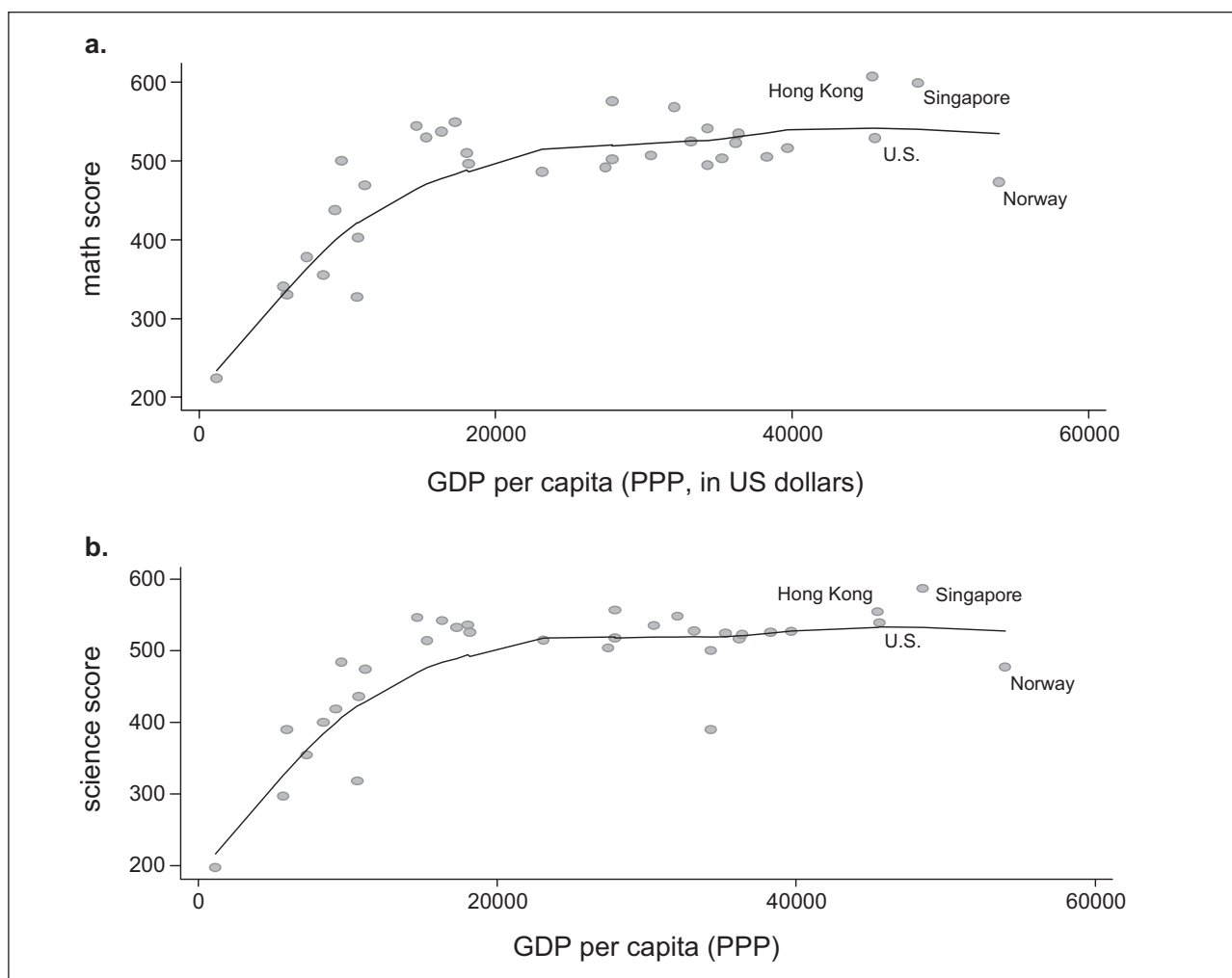


FIGURE 1 (a) TIMSS 4th grade math scores by annual GDP per capita (PPP), 2007. (b) TIMSS 4th grade science scores by GDP per capita (PPP), 2007. *Source:* Reprinted with permission from Xie and Killewald (2012). *Notes:* TIMSS = Trends in International Mathematics and Science Study. Individual scores range from 0 to 1000. Gross domestic product (GDP) per capita is adjusted for purchasing power parity (PPP) using Penn World Table Version 6.3. The GDP of the United Kingdom is used for England and Scotland. Kuwait is an outlier and removed from the analysis.

the United States and several other notable countries identified. In addition to Hong Kong and Singapore, other, unlabelled countries with higher scores than those of the United States (i.e., with dots above the line) are Japan, England, and the Russian Federation. In each figure, we present a flexible but smooth regression line that best describes the relationship between the TIMSS scores and GDP. For both math and science, the line of best fit shows that, at lower levels of per capita GDP, increasing financial resources are associated with sharp increases in test scores, but the subsequent flattening out of the line shows that further increases in resources lead to little additional gain in scores.

The United States falls just below the line in math and just above it in science, performing about as expected given its economic prosperity. But Hong Kong and Singapore, whose GDP per capita is similar to that of the United States, are above the line in both subjects, exceeding the performance of American youth. The TIMSS results for 8th graders indicate that students in the United States perform slightly worse than expected, given their financial resources, although the difference is larger in math.³

³ For a discussion of the differences between the TIMSS and PISA samples and content, see *Science and Engineering Indicators 2010* (NSB 2010, p. 1-16).

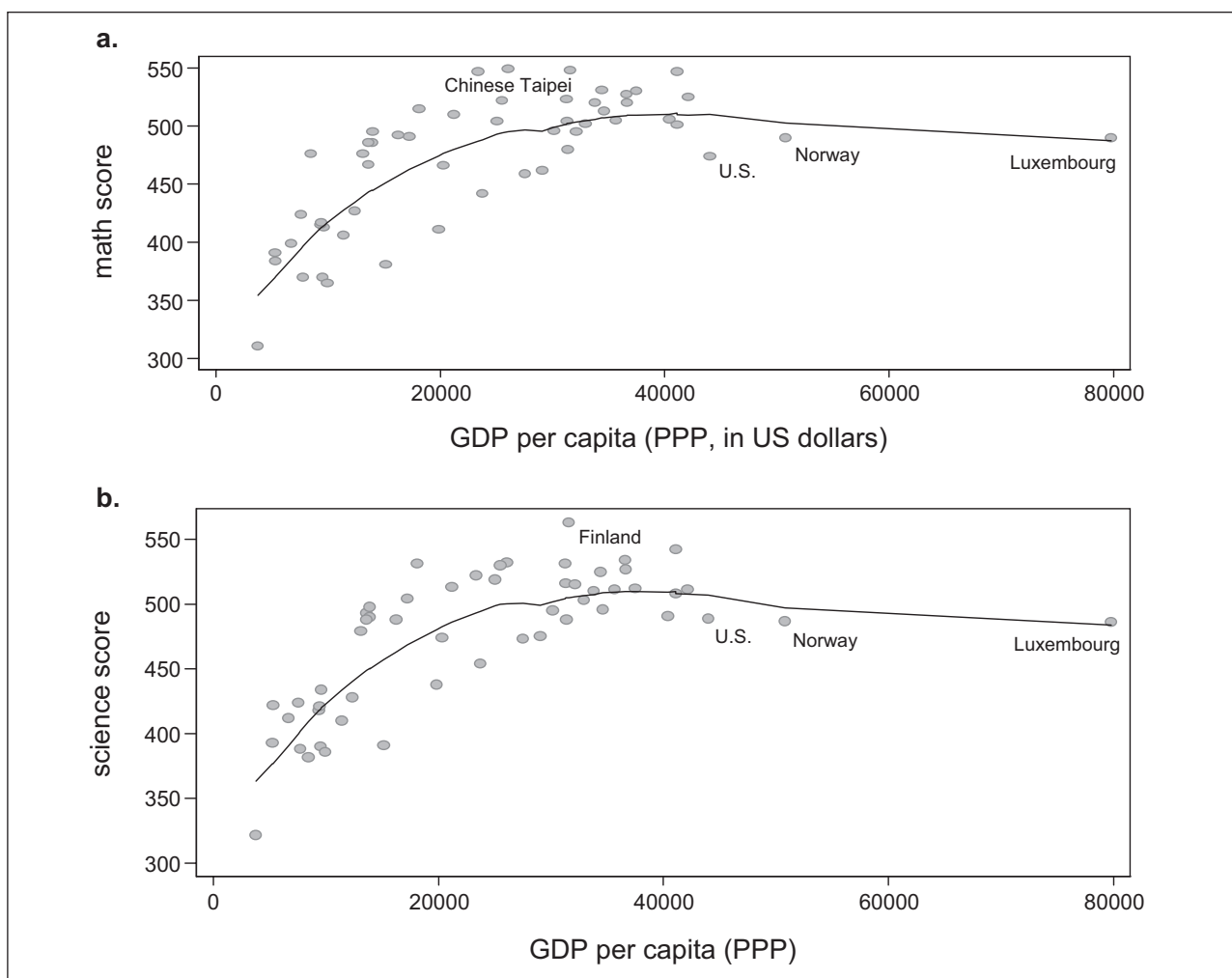


FIGURE 2 (a) PISA math scores by GDP per capita (PPP), 2006. (b) PISA science scores by GDP per capita (PPP), 2006. *Source:* Reprinted with permission from Xie and Killewald (2012). *Notes:* PISA = Program for International Student Assessment. Individual scores range from 0 to 1000. GDP per capita is adjusted for purchasing power parity (PPP) using Penn World Table Version 6.3. Serbia and Liechtenstein were excluded from the analysis because their GDP per capita for 2007 was not available from Penn World Table 6.3. Kuwait and Qatar are outliers and removed from the analysis.

Results from PISA in 2006, shown in Figure 2, are somewhat less favorable for US students: they fall below the line of best fit in both math and science, although the disparity is greater in math. The top spots went to Taiwan (designated Chinese Taipei in the PISA data) in math and Finland in science. Other countries whose students outperformed their US peers on this test are Japan, Australia, and Hungary.⁴

Thus the pattern that emerges from these figures is one of comparatively mediocre performance by

American students despite access to considerable economic resources.

American Science Education from a Historical Perspective

Concern about US students' rather poor performance in math and science relative to that of youth in selected other countries must be distinguished from the concern that American youth may not be performing as well as in the past. In this section, we change the comparison group for contemporary American schoolchildren to previous cohorts of Americans. We find little evidence that US math and science education is worse today than in past decades. If anything, it may be better, especially in math.

⁴ For this analysis, we excluded Kuwait and Qatar, both outliers because of their very high GDP and poor test results, to avoid their exerting undue influence on the regression line.

The National Assessment of Educational Progress (NAEP) has tracked trends in US students' knowledge of various academic subjects since the 1970s. From 1973 to 2008, the average math scores of both 9- and 13-year-old students increased significantly, while those of 17-year-olds remained flat. Furthermore, gains have been larger for African American and Hispanic students than for white students during this period, reducing the racial gap in math achievement (NCES 2009).

No assessment of the trend in US students' average achievement in math is, however, fully informative about trends in the potential pool of scientists, who are disproportionately drawn from the top part of the academic distribution. Has there been a decrease in the performance of American students with the highest levels of academic achievement in science-related subjects? Again, this does not appear to be the case. The math scores of students at the 90th percentile rose significantly between 1978 and 2008 for 9- and 13-year-olds, while remaining flat for 17-year-olds (NCES 2009).

Furthermore, among 17-year-olds, in 2008 19 percent had taken precalculus or calculus, compared with only 6 percent in 1978 (NCES 2009). And the number of students both taking and passing Advanced Placement (AP) exams in math and science subjects rose rapidly between 1997 and 2008 (NSB 2010, Chapter 1, p. 1-37).

In summary, the data show that today's American schoolchildren are better prepared than their counterparts of three decades ago to enter advanced training in scientific fields.

Pursuit of Higher Education in Science

International competition is not the only area of concern for those who view American science education as troubled. In 1990, former University of California president and National Science Foundation director Richard Atkinson, in a well-publicized article in *Science* magazine, projected "significant shortfalls" of scientists "for the next several decades" (Atkinson 1990, p. 425). This concern about recruitment of talented young adults to scientific education and careers has been echoed numerous times, leading to a popular view that there has been "a growing aversion of America's top students—especially the native-born white males who once formed the backbone of the nation's research and technical community—to enter scientific careers" (Benderly 2010). However, the claims of a current or impending shortage have also

been challenged (Butz et al. 2003; Galama and Hosek 2008; Lowell and Salzman 2007).⁵

To address these concerns, we document trends in American undergraduates' pursuit of college-level scientific studies using longitudinal data on three cohorts of school-aged youth collected by the National Center for Education Statistics (NCES). Each cohort was followed through high school graduation and for at least eight years thereafter, with several follow-up interviews during this period. The NCES datasets provide information about the high school graduating classes of 1972, 1982, and 1992.⁶

We break down the process of degree attainment into two sequential steps: (1) attainment of a degree regardless of field and (2) attainment of college-level science education given a degree. In this way, we are able to distinguish trends in the pursuit of higher education more generally from trends in the pursuit of a science degree among all who receive a bachelor's degree.

US schoolchildren today are better prepared than their counterparts of three decades ago to enter advanced training in scientific fields.

The first two rows of Table 1 show the unadjusted trends across the three cohorts in the likelihood of receiving a bachelor's degree. The fraction of men receiving a bachelor's degree rose modestly, from 27.8 percent in the 1972 cohort to 30.5 percent in the 1992 cohort. For women, the rise was more substantial, from 23.9 percent to 36.9 percent. Students with high

⁵ Atkinson's *Science* article has been widely criticized, and he himself later admitted that some of its assumptions were flawed, especially where immigration was concerned (Atkinson 1996).

⁶ The data for each cohort are from the National Longitudinal Study of the Class of 1972 (NLS-72), High School and Beyond (HS&B), and the National Education Longitudinal Study (NELS:88, which tracked a cohort of students from their 8th grade year in 1988 through their senior year of high school in 1992). Information about these surveys is available at the NCES website, <http://nces.ed.gov/>.

TABLE 1 Bachelor's Degree and Science Major Attainment, by Gender and Cohort (percent)

	Male			Female		
	1972 cohort (NLS-72)	1982 cohort (HS&B)	1992 cohort (NELS)	1972 cohort (NLS-72)	1982 cohort (HS&B)	1992 cohort (NELS)
Bachelor's degree	27.8	30.7	30.5	23.9	29.8	36.9
Among top 25% in math achievement	54.5	61.2	64.3	53.5	70.4	75.9
Science major given bachelor's degree	28.7	31.4	28.3	10.2	13.7	13.2
Among top 25% in math achievement	36.9	41.5	38.8	15.7	20.9	19.3
Science subfields given bachelor's degree						
Physical science	7.4	3.4	3.1	3.6	1.3	1.6
Life science	9.6	5.0	8.1	4.6	5.3	8.3
Mathematical science	1.3	2.1	1.6	1.6	1.1	0.9
Computer science	1.1	5.6	3.2	0.1	4.1	0.8
Engineering	9.4	15.6	12.4	0.3	2.1	1.7

Note: The sum of percentages across the science subfields does not exactly equal the percentage of science major due to double-majoring and rounding. HS&B = High School and Beyond, class of 1980; NELS = National Education Longitudinal Study of 1988; NLS-72 = National Longitudinal Study of the Class of 1972.

Source: Reprinted with permission from Xie and Killewald (2012).

mathematical aptitudes (defined as having scored in the top 25 percent on the mathematics test given in each survey) generally had high rates of completing a bachelor's degree (above 50 percent). Men in this category increased their completion rates from 54.5 percent in 1972 to 64.3 percent in 1992, and women increased their rates by a larger margin, from 53.5 percent for the 1972 cohort to 75.9 percent for the 1992 cohort.

The next two rows present trends in the likelihood of receiving a bachelor's degree in science or engineering (S/E) conditional on having received a bachelor's degree in some field. For men, there is no clear trend: the fraction of college graduates receiving an S/E degree is between 28.3 percent and 31.4 percent. For women, there is an increase in the pursuit of science across cohorts, from 10.2 percent of college graduates in the 1972 cohort to 13–14 percent in the later cohorts. Even so, although women made slight inroads in scientific training over this period, male college graduates in the most recent cohorts were still more than twice as likely as their female counterparts to receive degrees in S/E fields.

There is little evidence that science suffers a “leaky pipeline” during the college years that steers students away from scientific fields and toward nonscientific studies. Using data from the same sources on 12th grade students' expectations regarding their major in college, we find that, for the 1992 cohort, the share of actual S/E majors among bachelor's degree recipients is slightly higher than the share of expected S/E degrees among youth expecting a bachelor's degree. Among 12th grade boys expecting to attain a college degree, 27.5 percent expected it to be in science and 28.3 percent of male college graduates actually received a degree in science. For women the numbers are 10.5 percent and 13.2 percent, respectively. Thus actual science majors account for about the same share of graduates as expected science majors do of expected degree recipients.⁷

⁷ Students who expect to major in a nonscience field are less likely to complete any degree than their peers who plan to major in an S/E field. Some nonscience students also shift to an S/E major in college.

These patterns of science study among young men and women also hold true among students with high mathematical aptitudes. The likelihood of high-achieving men receiving S/E degrees was 36.9 percent in the 1972 cohort and 38.8 percent in the 1992 cohort; for high-achieving women the likelihood rose from 15.7 percent for the 1972 cohort to 19.3 percent for the 1992 cohort.

We further disaggregate the trend data on S/E degrees by field and present them in the last panel of Table 1. There is evidence of declining pursuit of physical science degrees among both men and women. In the 1972 cohort, 7.4 percent of male college graduates and 3.6 percent of female college graduates received a degree in physical science, but the comparable percentages in the 1992 cohort were only 3.1 percent and 1.6 percent. Offsetting this decline was an increase during the same period in the fraction of bachelor's degrees in engineering: among males it rose from 9.4 percent in the 1972 cohort to 15.6 percent and 12.4 percent in the later two cohorts, respectively, and for women the analogous numbers are 0.3 percent, 2.1 percent, and 1.7 percent. While engineering is the largest subfield of S/E majors for men, accounting for more than 10 percent of all male college graduates in the later two cohorts, it remains a far less common pursuit for women, never capturing more than 2.1 percent of a graduating cohort. Women's gains in attaining S/E degrees were concentrated in life science, the most popular scientific field for women: the fraction of female college graduates that received a degree in life science rose from 4.6 percent in the 1972 cohort to 8.3 percent in the 1992 cohort. Pursuit of math degrees has always been less common among students of either sex, and the share of math degrees declined across the cohorts for women, while showing no clear trend for men.

Beyond High School and College

Whereas we found little evidence that the supply of trained young scientists has declined in recent decades, critics of the shortfall argument contend that the United States in fact faces a crisis of a surplus of scientists, with too few jobs to employ them (Benderly 2010; NRC 2005). "The S&E [science and engineering] employment of S&E graduates is...a fairly consistent one-third of S&E graduates," claimed a 2007 report of the Urban Institute (Lowell and Salzman 2007, p. 30) in response to the 2007 report *Rising Above the Gathering Storm* (NAS/NAE/IOM 2007).

A government-sponsored official publication series, *Science and Engineering Indicators*, commonly considered the most authoritative source on scientific workforce statistics, has released estimates that seem to bolster this claim. The 2010 edition, for example, reported a large discrepancy (a ratio of about one to three) between the size of the S/E workforce and the number of individuals with a bachelor's degree or higher in science or engineering—"between 4.3 million and 5.8 million" for the workforce versus "16.6 million" individuals with science or engineering degrees (NSB 2010, Chapter 3, p. 3-6).

We evaluated this claim using both direct and indirect measures and summarize our results here. Most critically, we find that the aforementioned numbers are sensitive to the inclusion of social science majors as scientific majors. At the undergraduate level, social science majors are not tightly linked to a career in the social sciences but are similar to a liberal arts degree. The fact that many social science graduates do not pursue careers in the social or natural sciences pulls down the average transition rate for all scientists. This is important because, as an undergraduate major option, social science is much bigger than other S/E fields and has grown rapidly in recent years (NSB 2010, Figure 2-5). When we exclude social scientists, we find that the ratio between the numbers of actual and potential scientists is between 45 percent and 60 percent, more than the 1:3 ratio. Given that the outcry about the state of American science has mostly been about natural science rather than social science, we believe that ours is a more appropriate description of transition rates from S/E undergraduate education to scientific employment.

*International collaborations
facilitate scientific
achievements that benefit
the entire world.*

Impacts of Globalization

If current global trends continue, it is certainly possible that America will lose its long-standing dominance in world science. However, globalization does not necessarily come at the expense of American well-being.

Science increasingly requires collaborative efforts across national boundaries (NSB 2008, Chapter 5, pp. 5-2, 5-7), and such collaborations facilitate scientific achievements that benefit the entire world. Indeed, history shows that human societies have, for the most part, made significant advances in economy and culture only when technological knowledge was shared over different regions (Diamond 1999). Thus, rather than harming science in any one country, globalization may benefit scientific progress broadly.

To cite one high-profile recent example, the construction of the Large Hadron Collider at the European Organization for Nuclear Research (CERN) brought together scientists from nearly 60 countries to seek experimental evidence for the Higgs boson, a key prediction of the Standard Model of particle physics.⁸ The international collaboration enabled countries to both pool personnel and share the more than \$4 billion cost of building the world's largest particle accelerator (Brumfiel 2008).

There is also ample evidence that innovative ideas are most likely to emerge when people with different perspectives interact (Page 2007). The experiences and perspectives of scientists from different countries can make international collaboration highly productive for all. Furthermore, as with trading, comparative advantages can be exchanged for mutual benefits between scientists in different countries. Not least, participation in science by more nations means greater government investment in research overall and a larger science labor force worldwide.

Because a scientific discovery needs to be made only once but often has long-lasting and widespread benefits, globalization is certain to speed up scientific progress, for at least two reasons. First, there may be efficiency gains via complementarity, as scientists in different parts of the world may hold distinct advantages due to either unique natural resources (e.g., particular weather patterns or unusual plants) or unique intellectual traditions. Second, the sheer expansion of the scientific labor force means more opportunities to produce fruitful scientific results. Hence, globalization of science is beneficial to both science and humanity, and has the potential to benefit American science and society as a whole.

⁸ Information about the project is available from the National Science Foundation and US Department of Energy, "The US at the Large Hadron Collider," available online at www.uslhc.us/.

Conclusion

American science education is the very foundation for US science, economy, and security. For this reason, policymakers and the public alike have good reason to be concerned about its welfare. However, in evaluating its state, it is useful to keep a balanced and holistic perspective.

In aspects that we could measure with data, we did not find evidence that US science education has deteriorated. To the contrary, we see that it has improved over time. It is true, however, that in comparison with other countries, particularly some Asian countries, US students' performance on international tests is mediocre, especially relative to America's rich economic resources. However, this comparison reflects improvements in students' academic performance in these successful countries more than a decline or failure of American science education. To be sure, America has a lot to learn from other countries, but this point is different from condemning US science education altogether. Finally, we posit that learning from other countries that are more successful in science education is actually a benefit of globalization, which can enhance the well-being of the United States in the long run.

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Structural solutions are needed for the serious challenges in precollege contexts that impede efforts to broaden participation in engineering.

Engineering Diversity

Fixing the Educational System to Promote Equity



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Significant investments have been made over the past several decades to enhance the nation's science and engineering workforce by broadening participation in science, technology, engineering, and mathematics (STEM) and related fields. Thanks to these efforts, the numbers of women and African American, Latino, and American Indian men earning bachelor's degrees in STEM fields have generally increased (NSF 2011). But these groups are still highly underrepresented in many STEM disciplines.¹ In this article we address the persistent underrepresentation of minority men and of women from all racial/ethnic groups in engineering education and careers.

Although diversifying the engineering workforce requires intervention at all educational levels and at the critical transition from higher education to the workforce, we argue that the lack of diversity in the engineering

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¹ These groups are underrepresented relative to both their share of the general population and their presence in the higher education population

workforce arises from the experiences of these populations long before they enter college. Such experiences include differences in (1) access to appropriate coursework and quality education inputs (e.g., good teachers, laboratories); (2) expectations, and career information and counseling; and (3) engineering-related experiences outside of schooling. These “opportunity gaps” contribute to both disparate levels of academic preparation to pursue an engineering degree and knowledge gaps related to awareness of engineering as a profession, conceiving of oneself as an engineer, and understanding what it takes to get there. We conclude by outlining ways to surmount these challenges through the purposeful actions of educators, policymakers, higher education institutions, and professional organizations in partnership with members of the engineering profession.

We begin by illustrating the persistent underrepresentation of women and minorities among undergraduate engineering degree recipients and discussing its significance.

The Status of Women and Minority Men in Engineering

“Engineering has a diversity problem.” This pointed observation by Chubin and colleagues (2005, p. 74) succinctly conveys the disturbing reality that the US engineering workforce does not reflect the nation’s demographics or talent pool. Engineering undergraduate and graduate degree earners are predominantly white and male (NACME 2008; NSF 2011), and the same is true of engineering faculty and individuals employed in the profession (NACME 2008; NSF 2011). While engineering’s “diversity problem” extends along the entire educational and workforce continuum, we focus on the underrepresentation of women and minorities in engineering at the undergraduate level.

Women and minority men are not represented among engineering bachelor’s degree holders at the same levels as in undergraduate degree programs in general or in other STEM fields (Table 1). Unfortunately, in spite of efforts to improve the representation of women and minorities in engineering at the undergraduate level, progress has generally stagnated (Figure 1). Between 1990 and 2000, the proportion of engineering bachelor’s degrees awarded to white, Asian, and underrepresented minority (URM) women rose slightly, but in the ensuing decade each of these groups saw its share of such degrees decline. This decline is not occurring in all STEM fields, however; minority men have increased their share of engineering and other STEM bachelor’s degrees over the past two decades. The rate of increase has slowed significantly since the late 1990s, though, and minority men remain underrepresented relative to their share of all bachelor’s degrees (NSF 2011).

Strengthening the Workforce by Diversifying STEM

Engineering’s “diversity problem” is significant for a number of reasons. It has been argued that broadening participation in engineering will create a more equitable society, increase innovation by bringing diverse perspectives to bear on critical national and global problems (e.g., Chubin et al. 2005), and maintain American competitiveness in a globalized economy (NACME 2008; NAS/NAE/IOM 2011). While all of these rationales for diversifying engineering are compelling, the “competitiveness” argument has gained the most traction in recent years. The National Academies report *Rising Above the Gathering Storm* (NAS/NAE/IOM 2007) urged the cultivation of a larger US STEM workforce in the face of rising global competition. Others (e.g., NACME 2008) have pointed to changing US

TABLE 1 Share of Bachelor’s Degrees in All Fields, in Natural Sciences and Engineering, and in Engineering, by Race and Gender, 2010

	Underrepresented minority men	Underrepresented minority women	White women	Asian/Pacific Islander Women
All fields	6.8%	11.8%	36.3%	3.6%
Natural sciences and engineering	7.8%	6.3%	23.1%	5.0%
Engineering	9.6%	3.0%	10.5%	2.6%

Note: Underrepresented minorities are African Americans, Latinos, and American Indians/Alaska Natives.

Source: NSF (2011).

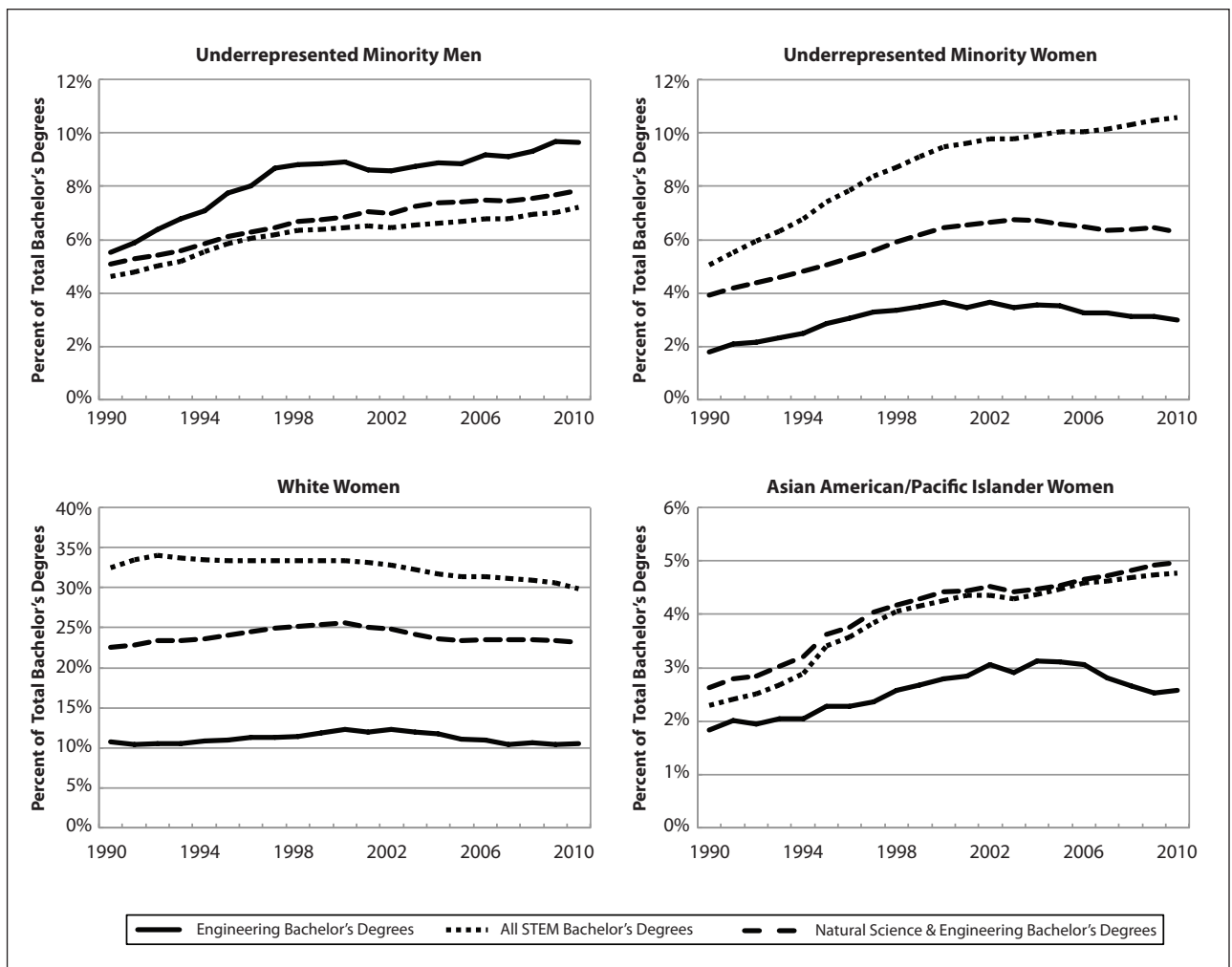


FIGURE 1 Trends in the percentages of total bachelor's degrees in all STEM fields, natural sciences & engineering, and engineering earned by underrepresented minority men, underrepresented minority women, white women, and Asian American/Pacific Islander women between 1990 and 2010. Underrepresented minorities are African Americans, Latinos, and American Indians. STEM fields are the biological/life sciences, physical sciences, mathematics, computer science, engineering, and social/behavioral sciences. Natural sciences and engineering are the biological/life sciences, physical sciences, mathematics, computer science, and engineering. *Source:* NSF (2011).

demographics as evidence that diversification of STEM fields must be a national priority, as increasing opportunity and participation in STEM among women and minority men will determine the nation's ability to compete in the global economy.

We note, however, that the “competitiveness” argument is not without controversy. Since the publication of *Gathering Storm*, there has been a robust debate about the STEM workforce crisis. Some (e.g., Lowell and Salzman 2007) have argued that US colleges and universities are producing an adequate supply—even an oversupply—of STEM degree holders. Others (e.g., Xie and Killewald 2012) emphasize the complexity of

the relationship between the STEM workforce and US global competitiveness, citing, for example, STEM areas with an oversupply (e.g., many biomedical fields), subfields with clear shortages (e.g., cybersecurity), and the impacts of an aging federal engineering workforce (e.g., NRC 2007). National security concerns also exist, as technical skills are needed among “clearable” US citizens. While a recent, comprehensive empirical analysis gives a “clean bill of health” to the current US STEM enterprise (Xie and Killewald 2012), the outlook for the engineering workforce quickly becomes murky if ongoing efforts to diversify the profession do not succeed. This is particularly true given current demographic

trends, in which women and minorities account for an increasing share of the US population and postsecondary enrollments.

Successful efforts to broaden participation in engineering require understanding of the challenges and barriers to recruiting, retaining, and graduating more women and URM men from engineering undergraduate degree programs. Only then can appropriate and effective interventions be implemented.

The Challenges to Diversifying Engineering: Starting in K-12

The persistent underrepresentation of women and minorities is attributable to many factors that limit opportunities to pursue engineering at different points along the educational continuum. Because of the complex ways in which race and gender interact to affect educational opportunity in the United States (e.g., Oakes 1990), the points of greatest loss vary among demographic groups.

There has been a great deal of attention to the retention of women and URM students already enrolled in undergraduate engineering degree programs (e.g., Seymour and Hewitt 1997). While challenges to broadening participation in engineering in postsecondary educational environments are of great concern, national data (NSF 2011) consistently show that women and URM men are significantly less likely than white and Asian men to indicate even an intention to major in engineering upon college entry (Table 2). The racial/ethnic and gender disparities in intentions to pursue engineering are problematic, particularly in light of these populations' increasing share of undergraduate enrollments.

We argue that this "interest gap" originates from the disparate experiences of girls and minority boys in K-12 schooling environments. In this sense, it may be more accurately characterized as an "opportunity gap," originating from inadequate academic preparation, lack of exposure to engineering, tenuous personal identification with engineering, and inadequate knowledge about the steps necessary to pursue an engineering career. These factors prevent many women and minorities from embarking on engineering pathways.

Mathematics Performance

Recent data from the National Assessment of Educational Progress (NAEP) illustrate clear and disturbing racial inequities in mathematics and science achievement (Figure 2). Underrepresented minority

TABLE 2 Intention to Major in Engineering by Race and Gender, 2010

Race/ethnicity and gender	Percentage
All races/ethnicities	10.3%
Female	4.0%
Male	17.9%
White	10.5%
Female	4.0%
Male	18.0%
Asian	14.7%
Female	7.2%
Male	22.7%
African American	7.4%
Female	3.2%
Male	14.6%
Hispanic/Latino	9.3%
Female	3.2%
Male	18.2%
American Indian	5.6%
Female	1.6%
Male	11.2%

Source: NSF (2011).

students were significantly less likely to score at or above "proficiency"² on mathematics and science national assessment tests than whites and Asians in grades 4, 8, and 12 (DOEd 2009, 2011a).

Fortunately, the differences in mathematics achievement by gender are smaller, and statistically significant for only two racial/ethnic groups, whites and Latinos. White boys in the 4th, 8th, and 12th grades were more likely than girls to score at or above proficient levels in mathematics (Table 3). The size of the gap in mathematics performance remained roughly constant through elementary, middle, and high school. A gender gap in performance also existed among Latinos, with higher proportions of boys scoring at or above proficient levels in mathematics than their Latina counterparts in grades 4, 8, and 12 (Table 3).

²The NAEP defines three levels of achievement: basic, proficient, and advanced. Subject-specific definitions of each level are provided on the NAEP website, <http://nces.ed.gov/nationsreportcard/>.

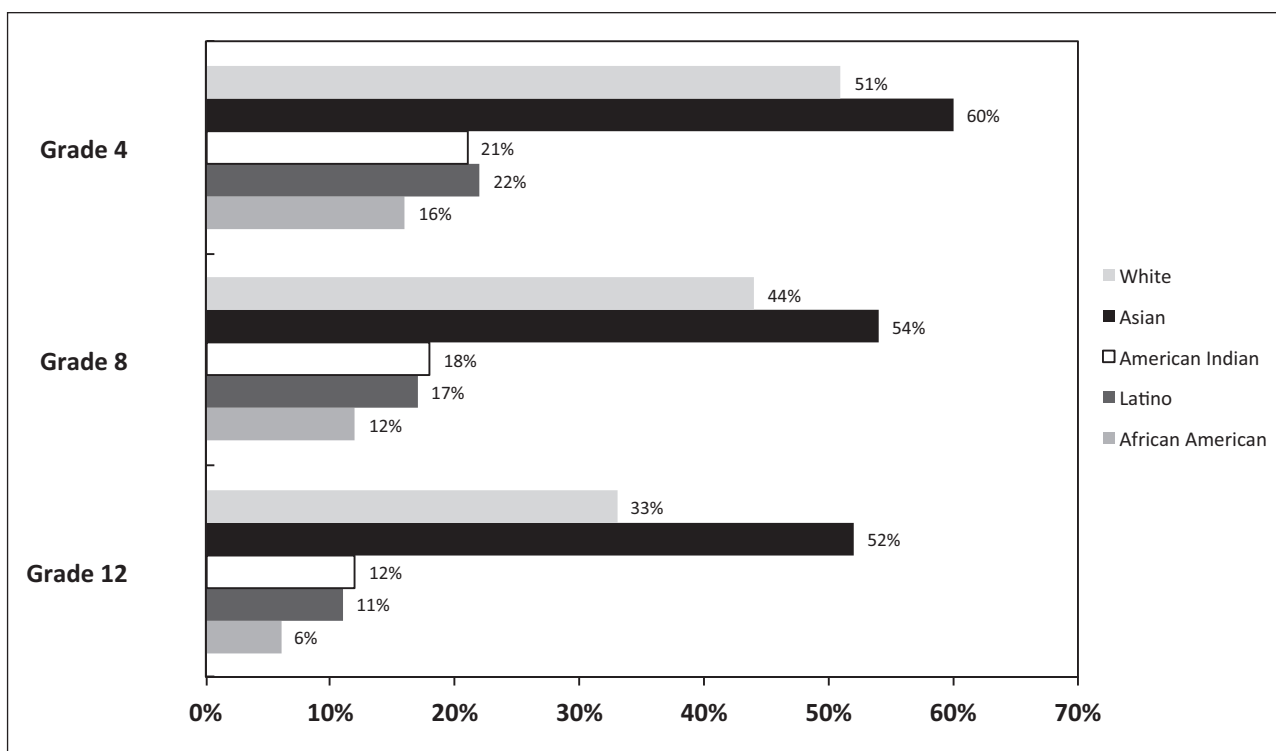


FIGURE 2 Racial/ethnic comparison of the percentages of 4th, 8th, and 12th graders who scored at or above proficient on the 2009 National Assessment of Educational Progress (NAEP) Mathematics Assessment. *Note:* The definitions of “proficient” and other achievement levels are provided on the NAEP website, <http://nces.ed.gov/nationsreportcard/subjectareas.asp>. *Source:* DOEd (2009).

Science Performance

Data on science achievement among the nation’s youth also reveal large race-based inequities throughout K–12 schooling (Figure 3). For example, in 2009, just 11 percent of African Americans, 14 percent of Latinos, and 17 percent of American Indians in the 4th grade scored at or above proficient levels in science, compared to 47 percent of white and 45 percent of Asian 4th graders. Similar patterns emerge from the data on science achievement in grades 8 and 12. As with the race-based gaps in mathematics performance throughout K–12, these stark inequities in science achievement likely set the stage for the disparate levels at which underrepresented minorities participate in engineering at postsecondary levels.

Table 4, which presents the 2009 NAEP science achievement levels for grades 4, 8, and 12 disaggregated by race/ethnicity and gender, reveals gender-based performance gaps in science achievement among certain demographic groups. In each of the three grade levels for which data are available, white males are more likely than white females to score at or above proficient levels on the science assessment. Statistically sig-

nificant differences in science achievement were also present among Latino 8th and 12th graders, with boys more likely than girls to score at or above proficiency in science.

Although the gender differences on the NAEP science assessment are small compared to the race-based disparities, they are still problematic, particularly when considered in light of gender-based science course-taking patterns.

Becoming “Engineering Eligible”: K–12 Science and Mathematics Course-Taking Patterns

The path to engineering does not begin upon college entry. Individuals who enter and are successful in engineering degree programs complete rigorous science and math coursework while in high school (Adelman 1998). Indeed, advanced courses such as precalculus, chemistry, and physics are necessary to be adequately prepared to pursue engineering in college, or “engineering eligible” (NACME 2008). Unfortunately, girls and underrepresented minorities are less likely than white and Asian males to complete such coursework in high school (DOEd 2011b), diminishing the diversity

TABLE 3 Proportion of Students Scoring At or Above “Proficient” on National Assessment of Educational Progress (NAEP) Mathematics Assessment by Race and Gender, 2009

Race/ethnicity	Grade 4		Grade 8		Grade 12	
	Male	Female	Male	Female	Male	Female
White	53%	48%	46%	42%	35%	30%
Asian	61%	60%	55%	52%	52%	51%
African American	16%	16%	12%	13%	6%	6%
Latino	23%	20%	19%	15%	13%	9%
American Indian	22%	21%	20%	17%	14%	10%

Note: The definitions of “proficient” and other achievement levels are provided on the NAEP website, <http://nces.ed.gov/nationsreportcard/subjectareas.asp>.

Source: DOEd (2009).

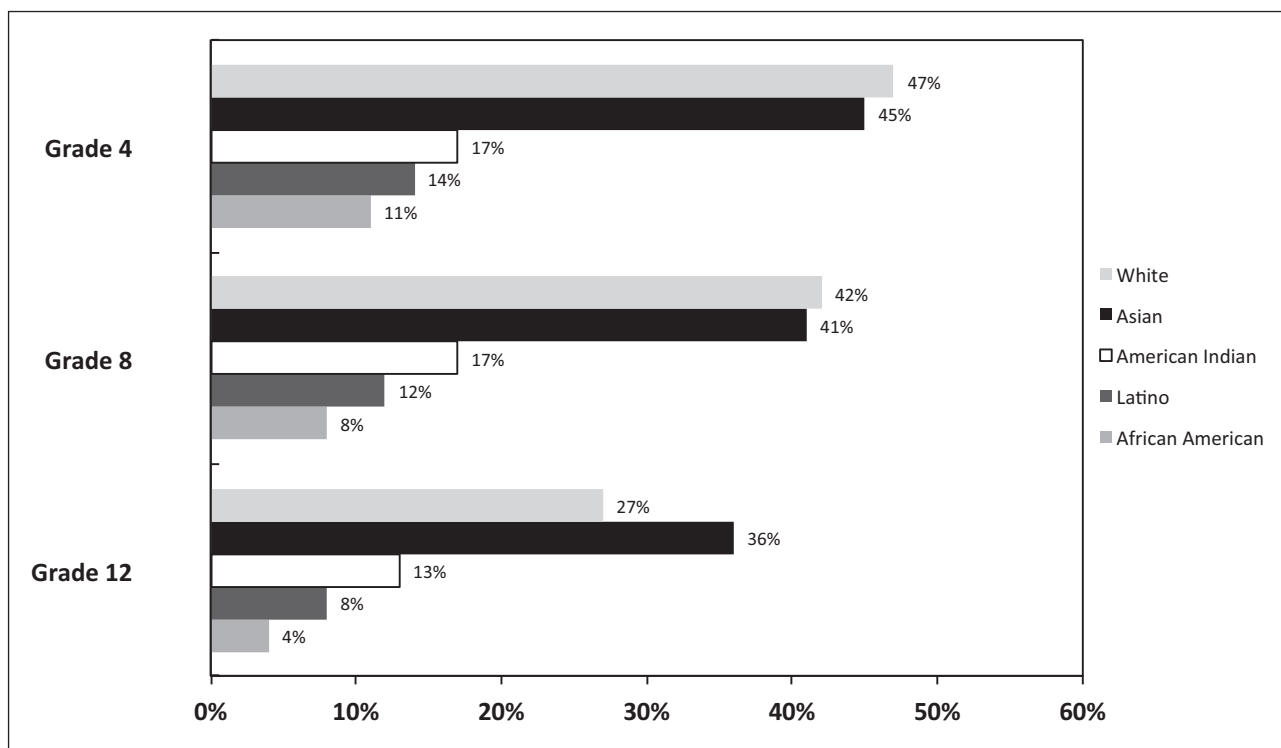


FIGURE 3 Racial/ethnic comparison of the percentages of 4th, 8th, and 12th graders who scored at or above proficient on the 2009 National Assessment of Educational Progress (NAEP) Science Assessment. Note: The definitions of “proficient” and other achievement levels are provided on the NAEP website, <http://nces.ed.gov/nationsreportcard/subjectareas.asp>. Source: DOEd (2011a).

of the pool of students prepared to study engineering in college.

Underrepresented minority students are also less likely to complete Algebra I before high school (Figure 4). This is significant because the timing of

this course determines how far a student advances in the mathematics course-taking sequence. Indeed, the consequences of this disparity are apparent in the lower rates at which URM students earn credits in precalculus in high school (Figure 4). These

TABLE 4 Proportion of Students Scoring At or Above “Proficient” on National Assessment of Educational Progress (NAEP) Science Assessment by Race and Gender, 2009

Race/ethnicity	Grade 4		Grade 8		Grade 12	
	Male	Female	Male	Female	Male	Female
White	49%	45%	46%	37%	32%	22%
Asian	44%	45%	44%	37%	32%	39%
African American	10%	11%	9%	8%	5%	4%
Latino	15%	13%	15%	10%	11%	6%
American Indian	17%	17%	22%	12%	‡	‡

‡Reporting standards not met.

Note: The definitions of “proficient” and other achievement levels are provided on the NAEP website, <http://nces.ed.gov/nationsreportcard/subjectareas.asp>.

Source: DOEd (2011a).

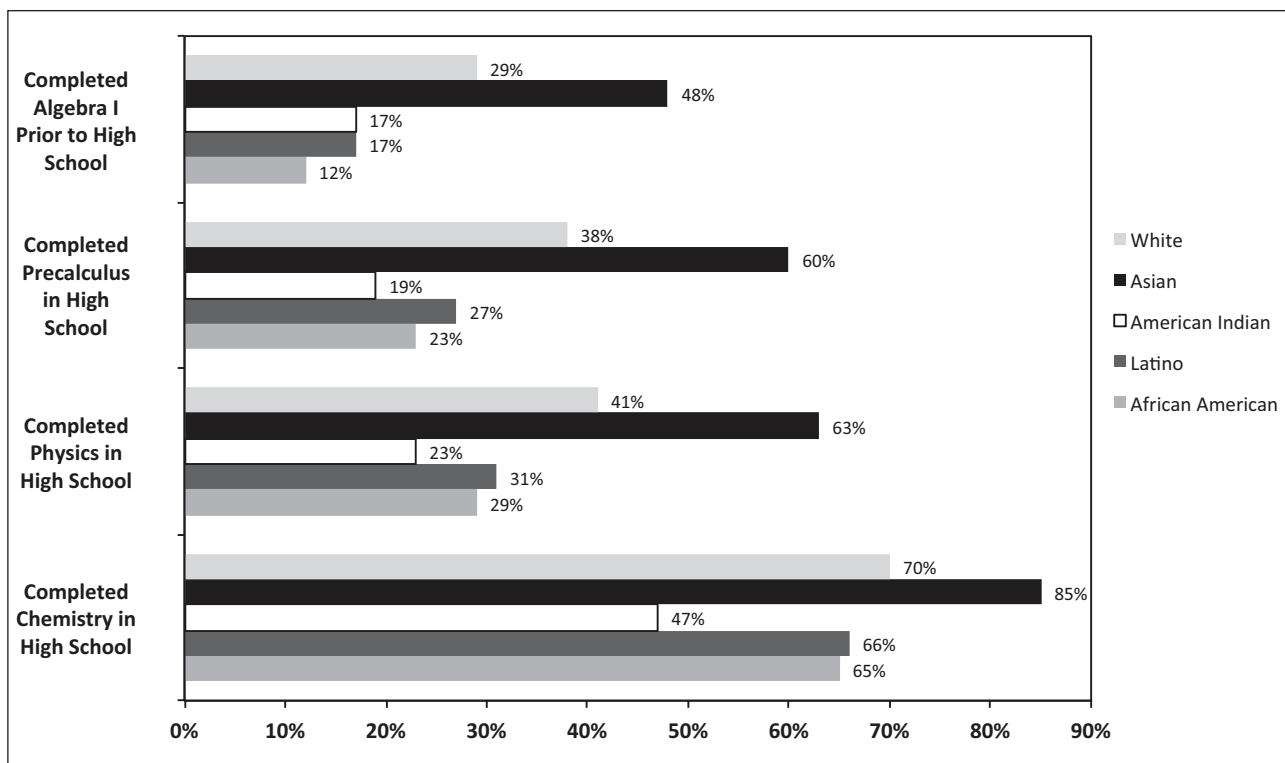


FIGURE 4 Racial/ethnic comparison of percentages of high school graduates who completed Algebra I prior to high school, earned credits in precalculus, physics, and chemistry. Source: DOEd (2011b).

inequities contribute to the lower rates at which underrepresented minorities enter engineering undergraduate degree programs, as students need precalculus in order to be considered engineering eligible. Similar patterns emerge from high school science

course-taking data (Figure 4); underrepresented minorities are significantly less likely to have taken physics while in high school (DOEd 2011b).

Interestingly, no gender-based differences in mathematics course-taking patterns appear in each racial/

TABLE 5 Science and Mathematics Course-taking Patterns by Race and Gender, 2009

Race/ethnicity	Completed Algebra I prior to high school		Took precalculus in high school		Took physics in high school		Took chemistry in high school	
	Male	Female	Male	Female	Male	Female	Male	Female
White	28%	31%	36%	40%	44%*	37%*	67%*	73%*
Asian	46%	50%	58%	63%	63%	63%	81%*	88%*
African American	11%	13%	20%*	25%*	29%	28%	60%*	70%*
Latino	16%	18%	25%	28%	32%	30%	65%	67%
American Indian	16%	18%	21%	17%	25%	22%	42%	51%

Note: The definitions of “proficient” and other achievement levels are provided on the NAEP website, <http://nces.ed.gov/nationsreportcard/subjectareas.asp>.

Source: DOEd (2009).

ethnic group: female high school graduates were as likely as their male counterparts to have taken Algebra I before high school and equally likely to have earned credits in precalculus. However, there were some differences in science course-taking patterns. White girls were significantly less likely than white boys to have taken a physics course before high school graduation. In contrast, white, African American, and Asian female high school graduates were more likely to have taken chemistry than their male counterparts (Table 5).

Sociocultural Factors

Given these race-based differences in course-taking patterns, it is not surprising that smaller proportions of URM students—just 4 percent on average—complete high school academically prepared to pursue engineering than do whites and Asians (NACME 2008). What causes these stark differences in academic preparation? Much of the problem is attributable to structural inequalities in K–12 schooling. Underrepresented minority students are more likely to attend underresourced schools in higher-poverty areas (DOEd 2012), and less likely to attend high schools that offer a rigorous curriculum including, for example, Advanced Placement (AP) coursework (ETS 2008). Furthermore, URM students who do attend highly resourced schools are less likely to enroll in college preparatory and AP coursework due to tracking and other discriminatory factors (e.g., stereotypes) (Oakes 1990). Not surprisingly, these inequities at the K–12 level lead to further inequities, as underrepresented minorities are less likely to attend selective

institutions that often offer a wider range of engineering degree programs (Bowen et al. 2005).

Beyond the academic challenges to diversifying engineering, a great deal of research has examined sociocultural factors that impede women’s and minorities’ progress down engineering pathways. These challenges relate to the ways gender, race/ethnicity, and the intersection of the two affect opportunities to pursue engineering careers by limiting exposure to and personal identification with engineering, as well as the extent to which women and minorities are mentored and socialized to pursue careers in engineering.

As early as middle school, girls exhibit lower levels of self-confidence in their math and science abilities than do boys who have demonstrated similar levels of achievement (Parajes 2005). This lack of self-confidence makes girls less likely to engage in experiences that require math and science skills, including experiences relevant to engineering (AAUW 2010). Women and URM men also find that their opportunities to pursue engineering are limited by negative stereotypes about their math and science ability and normative beliefs about “gender-appropriate” careers (AAUW 2010). Such stereotypes lead to inadequate socialization to engineering fields and fewer opportunities to engage in engineering experiences both in and outside of formal learning environments (AAUW 2010). These stereotypes about which groups are “cut out” for engineering—and which left out—are reinforced by a lack of women and minority engineers to serve as role models (AAUW 2010; Widnall 2000).

With these challenges in mind, the gender and racial/ethnic differences in student intentions to major in engineering are not all that surprising. However, given that women and minorities represent an increasing share of college-aged students, it is essential to find ways to turn these challenges into opportunities to diversify engineering. We suggest several measures to achieve that.

Measures to Improve Access and Opportunity

Greater Career Awareness

Notwithstanding efforts over the years, students and their families need encouragement and access to information at a much earlier stage than has typically been provided, through exposure to role models who look like them, information about the kinds of jobs done by persons with preparation in engineering, and examples to dispel the idea that engineering is solitary work. And both students and parents need to know that engineering and technical jobs have been quite resistant to recession-related unemployment and that they enjoy some of the smallest pay gaps between males and females (AAUW 2012).

More Engineering and Technology in the Precollege Curriculum

Increased career awareness needs to be accompanied by increased access to engineering concepts and ideas. The Next Generation Science Standards (www.nextgenscience.org), being developed by Achieve and based on the NRC *Framework for K–12 Science Education* (NRC 2012; see Schweingruber et al. 2013 in this issue), explicitly include engineering and technology and provide an opportunity to engage students meaningfully. The framework emphasizes equitable opportunity to learn and personal identification with problems. The greatest challenge will be in providing equitable access to individuals in the classroom (i.e., teachers and/or visiting professionals) who can incorporate this into their teaching and support student learning.

Quality Education

Unless and until the structure of educational opportunity is addressed it will be very difficult for schools to provide quality education for all students. As it is, access to rigorous courses, good teaching, adequate facilities, and appropriate equipment correlate with socioeconomic status and racial/ethnic group membership, and poor and underrepresented minority students receive

less of everything needed to successfully study STEM. Students at these schools need to have access to more AP and International Baccalaureate (IB) courses as well as programs such as the National Math and Science Initiative's Advanced Placement Training and Incentive Program (APTIP).

More After- and Out-of-School Experiences Connected to Engineering

Early efforts to increase the participation of females and underrepresented minorities in engineering education and careers started outside of school. Programs such as Expanding Your Horizons for female students and Mathematics, Engineering, Science Achievement (MESA) for minority students were established by university-level program advocates (e.g., Malcom et al. 1984). Programs for girls often emphasized the experiences and role model aspects of intervention, as well as interactions with parents to provide career information. Programs for minorities offered experiences as well as rigorous supplemental course content at a level needed for students intending to major in STEM fields. Sally Ride Science and AAAS' Spark Club (part of a suite of programs under NSF's Innovative Technology Experiences for Students and Teachers, ITEST) are examples of more recent programs that support STEM in the out-of-school space, along with a number of initiatives by science and technology centers, libraries, and others (e.g., www.afterschoolalliance.org). But just 19 percent of students have access to such programs (Change the Equation 2012). More efforts are needed to expand the opportunities to engage in science and engineering experiences after school and during summers. Communities must be engaged and relevant contexts created for students from different populations.

While the aforementioned intervention programs have had a positive impact on minorities' and women's pursuit of engineering education and careers, they exist outside the regular educational system and are often part of special projects with "soft" financial support. Moreover, many now face legal or judicial challenges because they targeted underrepresented populations. Uncertainty about their status has decreased the likelihood of their continuation and limited their ability to target underrepresented groups. And the extension of programs to other populations decreases the numbers of members of the originally targeted groups that can be served. The solution needs to be structural—to fix school systems so that opportunity is not stratified

by race and expectations are not driven by gender or racial/ethnic stereotyping about who does engineering and science.

Consideration of Unintended Consequences of Policy Shifts

Policies are often put in place to address a specific problem or concern that emerges at a particular time, but are not necessarily considered in the context of their impact on the larger system of which the problem is a part. Thus although the accountability measures put in place under the No Child Left Behind Act aimed to ensure attention to the education of all population groups, the focus on reading and mathematics and allowances for states to set their own minimum performance thresholds, or cut scores, have had serious unintended consequences. These include pushing other subject areas, such as science, out of the curriculum and lowering standards to “meet” performance goals.

Policymakers and policy advocates need to consider the possible consequences of proposed policies for STEM education and opportunity: Will increased reliance on international sources of STEM talent lessen the effort for or interest in supporting the development of domestic talent pools? What about proposed changes in immigration laws to retain international STEM talent? How might changes in financial aid policies affect access to engineering degree programs for qualified students with financial need?

Targeted Research

Support is needed for research, experimentation, and evaluation that can point to effective practices and refinement of instructional strategies and policies to “fix the system.” The findings of such research can eventually reduce the need for interventions and support the creation of institutions that work for all.

Conclusion

Efforts to address engineering’s “diversity problem” require attention to critical issues along the entire educational pathway. We have identified some of the serious challenges in precollege contexts that have impeded long-standing efforts to broaden participation in engineering. Although we have outlined some ways in which educators, professional organizations, and members of the engineering professions can work to turn these challenges into opportunities, these actors must come together to develop and implement inno-

vative ways to further enhance diversity. Doing so will ensure a high-quality engineering workforce and the long-term sustainability of pathways to engineering for all students.

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Ongoing challenges to policies that have historically expanded access and opportunity for underrepresented minorities and women in STEM require new strategies to help widen the pipeline of diverse students in the future.

Promoting Access to Undergraduate STEM Education

The Legal and Policy Environment



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Greater diversity in the science, technology, engineering, and mathematics (STEM) fields not only sets the stage for a robust 21st century workforce but also contributes to educational and research environments that reflect and draw on diverse perspectives for stronger science (NAS/NAE/IOM 2011). But women and America's fast-growing racial and ethnic populations remain highly underrepresented in these fields. Higher education policies that have historically expanded access and opportunity for underrepresented minorities and women on college campuses have included the consideration of race, ethnicity, and/or gender as an "affirmative" factor in admissions. Such policies, however, are the target of legal and public debate that compels new thinking about complementary strategies to help widen the pipeline of diverse students who will pursue STEM studies and careers.

In this article, we provide an overview of the current status of underrepresented minorities (URMs) and women in US STEM higher education and of the shifting legal and policy climates surrounding affirmative action policies at colleges and universities nationwide. We make the point that—given the uncertain future of race-conscious admissions policies, declines

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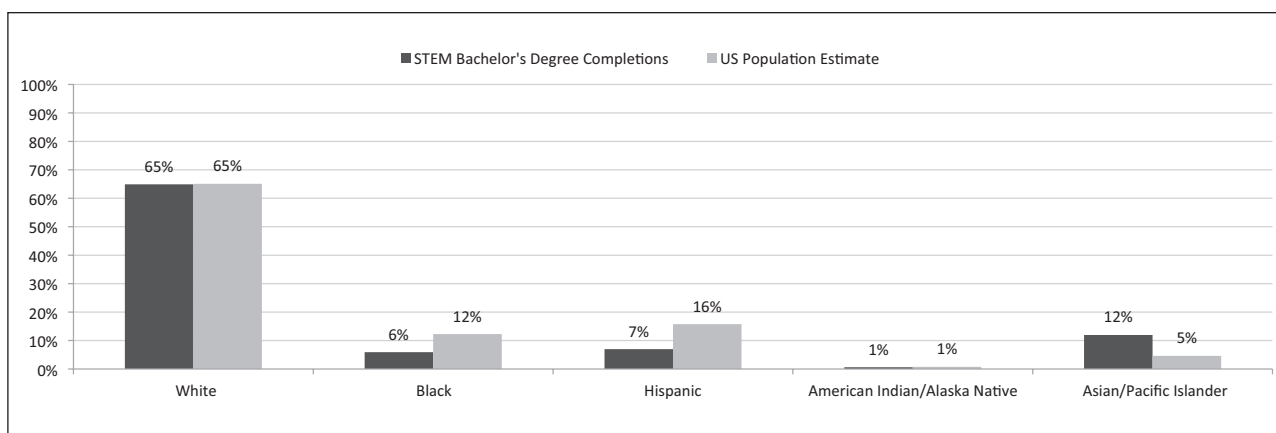


FIGURE 1 Percentage of science, technology, engineering, and mathematics (STEM) bachelor's degree completions relative to census population estimates by race/ethnicity, 2009. *Source:* Rodriguez et al. (2012).

in racial and ethnic diversity at postsecondary institutions in states that have banned affirmative action, and the negative long-term consequences of these declines for the nation—institutions must explore alternative strategies for increasing participation and careers in STEM. For many students, access and exposure to college environments and supportive role models and mentors can make a world of difference for expanding access to STEM fields, so we describe promising outreach and partnership strategies at the college and K–12 levels.

The Status of Underrepresented Populations in STEM

According to Census Bureau projections (Vincent and Velkoff 2010), the aggregate US minority population will become the majority by 2042. Latinos alone are projected to make up 19 percent of the US civilian labor force by 2020 (Toossi 2012) and nearly one-third of the country's population by 2050 (Passel and Cohn 2008). Yet the fastest-growing populations are also those most underrepresented in higher education generally and STEM in particular. And although women are the majority of college students, they remain severely underrepresented in certain STEM fields, including engineering and computer science.

A recent study conducted by the American Institutes for Research presents trend data on bachelor's degree completion by gender, race/ethnicity, and STEM discipline from 1989 to 2009 (Rodriguez et al. 2012). A comparison of the data for US demographic trends against bachelor's degree attainment in STEM fields reveals a troubling picture of lost opportunity

for underrepresented minorities. As Figure 1 shows, although Latinos made up 16 percent of the US population in 2009, they received just 7 percent of STEM bachelor's degrees. Similarly, African Americans represented 12 percent of the population in 2009 but earned just 6 percent of STEM degrees. And although men and women represent roughly the same proportion of the population, the gender gap persists in certain STEM disciplines, with the greatest inequities in engineering and the computer sciences (Figure 2).

Finally, perhaps in part because of their lower representation in higher education, as a *proportion* of STEM degree recipients, minority women and men are greatly underrepresented in their respective gender group. African American and Latina women earned just 5 percent (each) of STEM bachelor's degrees awarded to women in 2009, and American Indian/Alaska Native women earned just one half of 1 percent. Of STEM bachelor's degrees awarded to men in 2009, African Americans earned only 3 percent of degrees, Latinos 4 percent, and American Indian/Alaska Natives 0.3 percent. In raw numbers, however, minority men earned slightly more STEM degrees than did minority women, and, as with majority students, they typically earn more degrees than minority women in fields such as engineering, where they earn roughly two out of three degrees.

While the education policy community has turned more attention over the years to narrowing achievement gaps at all levels, it remains the case that secondary education has a particularly important role in ensuring access to college—and preparedness for STEM studies—for underrepresented groups.

Colleges and universities are gatekeepers to the majority of STEM careers. According to the Georgetown Center on Education and Workforce, by 2018, the majority of STEM jobs will require at least some college, with a full 41 percent requiring a bachelor's degree (Carnevale et al. 2011). To meet both the demand for STEM talent and the scientific, technological, and environmental challenges of this century, all US citizens should have the tools to enter and succeed in college STEM majors.

Shifting Legal and Policy Climates

A long-standing practice for institutions of higher education to help increase access for underrepresented groups is affirmative action: the consideration of race and/or ethnicity as a factor, among others, in the admissions process (see Bowen and Bok 1998; Bowen et al. 2005). As institutions implemented these efforts to address the cumulative effects of racial discrimination and remedy educational inequities, legal developments subsequently shifted this rationale to include educational and democracy-based justifications.

Supreme Court Cases

In the 1978 ruling in *Regents of the University of California v. Bakke*, Justice Powell (the controlling opinion in the case) rejected the use of race-conscious admission

policies to address the effects of past discrimination, endorsing their use, instead, for the purpose of attaining a diverse student body that would further the educational missions of postsecondary institutions.

Legal challenges persisted, however, and, after sustained litigation, the US Supreme Court in 2003 endorsed the limited use of race as a factor in admissions (*Grutter v. Bollinger*). In an opinion authored by Justice O'Connor, the Court held, as Justice Powell had in *Bakke*, that universities could consider race under strict limits to further a compelling interest in the educational benefits of student body diversity. Importantly, the Court's decision also expanded the justification for race-conscious policies beyond securing the educational benefits of a diverse student body to considering the broader implications of diversity for society and the nation.

The majority opinion in *Grutter* emphasized the role of universities and professional schools in providing "the training ground for a large number of our Nation's leaders" (*Grutter*, 539 US at 332). The Court also stressed the need for these institutions to be inclusive of individuals of all races and ethnicities so that they can have "confidence in the openness and integrity of the educational institutions that provide this training" (*Grutter*, 539 US at 332). With this expanded rationale, the Court recognized the important role of postsecondary institutions in

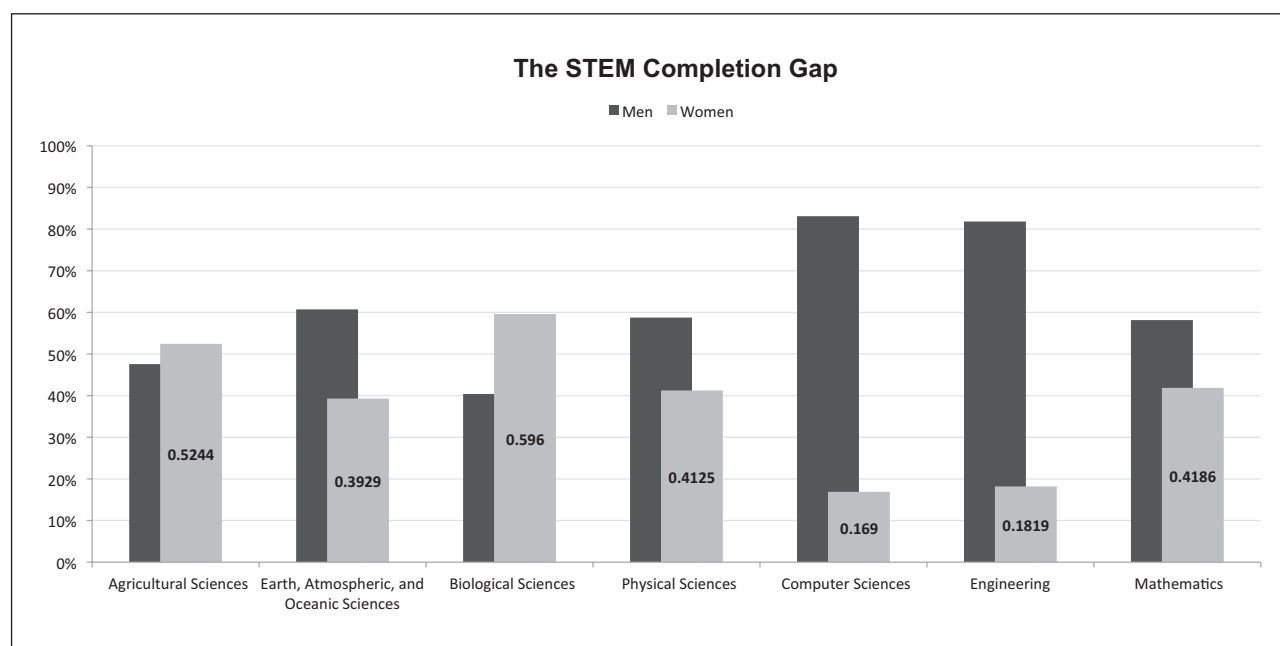


FIGURE 2 Percentage of undergraduate science, technology, engineering, and mathematics (STEM) degrees completed by men and women in 2009, by discipline. Source: Rodriguez et al. (2012).

sustaining the health of the US democracy by having a student body that more closely reflects the racial/ethnic diversity of the United States (e.g., Bowen et al. 2005).

The educational and democracy-related justifications for race-conscious admissions practices at postsecondary institutions are especially relevant to diversity efforts in STEM. In these fields, diversity is critical for understanding the issues being researched, addressing the needs of diverse communities, preparing individuals for effective professional practice in multiracial settings, and fostering creativity and innovation through the embrace of multiple perspectives (see, e.g., Harvey and Allard 2011; Page 2007). Diversity improves the quality of education for all students as the skills acquired through interaction with racially diverse peers have a lasting effect on individuals' preparation for employment in an increasingly diverse and global workforce.

Educational and democracy-related justifications for race-conscious admissions practices are especially relevant to diversity efforts in STEM.

But consideration of race as an affirmative factor in admissions remains the target of legal and public debate. The Court is now revisiting the topic in *Fisher v. University of Texas*, a case that is likely to affect the admissions practices of higher education institutions across the nation and may restrict the Court's holding in *Grutter*. At issue is whether the University of Texas at Austin's admissions policy, which considers race as one of many factors, is necessary to further the educational benefits of diversity. In *Fisher*, one of the Court's liberal justices, Justice Kagan (who replaced Justice Stevens) has recused herself, as she worked on the case on behalf of the Obama administration when she served as solicitor general. The final vote, therefore, could be a 4-4 decision (which would leave in place the Fifth Circuit's decision upholding the constitutionality of the university's race-conscious admissions policy) or another configuration of

votes that could overrule the Fifth Circuit's decision and restrict *Grutter*.¹

State-Level Actions

Debates over affirmative action are active at the state level as well. States are free to pass laws that prohibit affirmative action at public institutions, and eight states have done so. Of these, six (Arizona, California, Michigan, Nebraska, Oklahoma, and Washington) implemented the bans through voter-approved initiatives or referenda, and two banned the practice by executive decision (Florida) and legislative vote (New Hampshire). These bans have led to substantial declines in student racial/ethnic diversity, particularly at selective colleges and universities (see, e.g., Backes 2012; Hinrichs 2012; Tienda et al. 2003), in the professional fields of law (Kidder 2003) and medicine (Steinecke and Terrell 2008), and in other fields of graduate study (Garces 2012).

Diversity in graduate programs has decreased the most in the very science fields that are critical for the nation's continued scientific and technological advancement. For example, affirmative action bans at public institutions in California, Florida, Washington, and Texas have led to a 26 percent fall in the percentage of engineering graduate students who are Latino, African American, or Native American, and a 19 percent reduction in the natural sciences (Garces 2013).

Ramifications

If the Court in the *Fisher* case decides to limit the ability of institutions to consider race in admissions, then, as in states where the consideration of race in admissions has been banned by ballot initiatives and other measures, institutions may witness further enrollment declines among minority men and women. This development could have long-term, detrimental consequences for institutional outreach, recruitment, and support efforts for students in STEM fields and ultimately for American leadership in industry, defense, and basic and applied science.

¹ Since the 2003 *Grutter* decision, Justice O'Connor has been replaced by Justice Alito, one of the more conservative justices on the Court who voted with Chief Justice Roberts and Justices Thomas and Scalia in the Court's most recent education case to deny K-12 schools a compelling interest in maintaining racial diversity (*Parents Involved in Community Schools v. Seattle School District No. 1*, 2007).

A homogeneous STEM student body also tends to reinforce an already “chilly climate” for minority women. The social and cultural climate in STEM fields is a leading barrier to the perseverance of women of color in STEM careers (Ong et al. 2011). A large survey study of women of color in STEM graduate programs (Brown 1994, 2000) revealed that isolation, racism, and being racially/ethnically identifiable are greater challenges to their persistence than factors such as financial aid. Thus, a reduction of even one or two students of color in a STEM program can undermine the possibility of other URM students’ persevering in the program.

There may also be long-term effects on faculty diversity in STEM fields since doctoral training and graduate degree acquisition feed into faculty positions. Faculty play a critical role in influencing students’ decisions to attend graduate school, choose a program, and pursue a STEM career (Gasman et al. 2009; Ong 2002; Sader 2007). Faculty perspectives and research trajectories also have long-lasting effects on scientific inquiry (Espinoza 2011). Declines in the number of students of color thus affect the future composition of STEM faculty, the educational experiences of students, and the types of research conducted.

Promising Practices Moving Forward

Support and Outreach at the K–12 Level

Of course the first step to solidifying a diverse STEM student body and subsequent workforce is to strengthen the role of higher-education stakeholders in ensuring access to scientific college majors. To do this, effective outreach to K–12 students is important to ensure a stream of potential freshmen from diverse backgrounds and to fulfill institutional commitments to serve local communities. While an institution’s admissions office is certainly responsible for such activities, as are university outreach programs that target diverse populations, it is critical that STEM faculty actively support outreach programming and work in conjunction with outreach professionals. In addition to becoming involved in on-campus recruitment activities, particularly those aimed at attracting URMs and potential STEM students, faculty and staff can seek extramural (federal, philanthropic, corporate) funds and build diversity-focused activities (also called “broadening participation”) into research and development grant proposals.

One of the most effective ways to get students interested in studying STEM is to get them to a college campus, into a laboratory, or onto an industry campus. The

success of science museums in piquing the interest of young learners can be replicated by exposing students to cutting-edge technologies.

It is also critical that K–12 students be exposed to role models in STEM and be connected with mentors who can show them that the path to a STEM career is achievable, as illustrated in programs such as MIT’s Saturday Engineering Enrichment and Discovery (SEED) Academy and community networks such as Los Angeles’ Great Minds in STEM.

It is critical that K–12 students be exposed to role models in STEM and be connected with mentors who can show them that the path to a STEM career is achievable.

Groups dedicated to progress for girls and women in technology—many with impressive online resources and networks—include Girl Geeks, dot diva, EngineerGirl, the Society of Women Engineers, Anita Borg Institute, National Center for Women and Information Technology, and the Ada Project at Carnegie Mellon University (a leader in enrolling and graduating women in computer science). Also available are national networks (e.g., STEMconnector.org) and numerous state-based networks that facilitate collaboration across K–12 and higher education, government, and private industry. In short, there are a number of promising models and networks for faculty and staff to explore, emulate, or adapt.

But outreach activities are no panacea. Much needs to occur at both the pre-K and K–12 levels to ensure that all students have access to support systems that celebrate high achievement and provide quality education, advanced coursework, and seamless transitions across grade levels. Higher education has a role as well, and would do well to strengthen research and teacher training in schools of education.

Partnerships at the College Level

The debate over affirmative action has focused primarily on the use of this policy at elite or selective institutions.

Indeed, it is vitally important that students of color be welcomed at selective institutions as attendance is associated with greater benefits for all students, including higher degree completion rates (Alon and Tienda 2005) and enrollment in graduate or professional school (Mullen et al. 2003). Graduation from more selective institutions also leads to higher earnings and job success, particularly for Latinos and African Americans (Bowen and Bok 1998; Gandara and Maxwell-Jolly 1999). For these and other reasons, to create a more welcoming environment for URM and women students, departmental and institutional leadership should, among other things, reward diversity gains by faculty as part of the promotion and tenure process.

But elite institutions enroll a small proportion of America's undergraduate student body and a small fraction of URM students. Thus, one important and complementary strategy for increasing participation in STEM is to invest in institutions where minority students are most likely to enroll—community colleges, minority-serving institutions, and public colleges and universities.

Policy makers, educators, and industry leaders are right to recognize the importance of community colleges. Two-year colleges enroll 44 percent of the total American undergraduate population—and 54 percent of Native American undergraduates, 51 percent of Latino, 44 percent of African American, and 45 percent of Asian American/Pacific Islander undergraduates (AACC 2012). Four-year institutions and their faculty would therefore be wise to foster relationships with community colleges with the goal of building a pipeline of potential STEM transfer students. Such pipeline strategies will not only benefit students but strengthen the academic environment on both types of campuses.

Also important is the current and potential role of four-year minority-serving institutions (MSIs), which see their students through to graduation at higher rates than predominantly white campuses. While the latter graduate more African American and Latino STEM students in raw numbers, a larger proportion of the MSI student body enrolls and graduates in the STEM fields (Rodriguez et al. 2012).

Moreover, historically black colleges and universities (HBCUs) are known for the success of their STEM graduates. According to the National Science Foundation (Burrelli and Rapoport 2008), the top eight baccalaureate institutions for African Americans who later earned science and engineering PhD degrees were HBCUs. While institutional contexts certainly differ

across campuses, predominantly white institutions can learn a lot from MSIs, including HBCUs, with strong track records for degree production in STEM. Creating and strengthening relationships with these institutions could further enhance STEM pipeline efforts.

The formation of effective partnerships is at the heart of a recent report from the American Association for the Advancement of Science in collaboration with EducationCounsel (Coleman et al. 2012). *The Smart Grid for Institutions of Higher Education and the Students They Serve* is a guidebook with practical steps to effective collaborations between two- and four-year institutions, across four-year institutions, and between undergraduate and graduate programs. Like its predecessor, the *Handbook on Diversity and the Law* (Burgoyne et al. 2010), the guide was written in conjunction with legal experts so that institutions can move forward in confidence knowing that their programs will be both effective and legally sustainable.

Conclusion

Considering the current and projected makeup of the US population, it is clear that to continue to excel in STEM and lead the world in addressing today's toughest scientific and technological challenges, American higher education must increase the representation of women and students of color in the STEM fields. The country's potential to innovate and thrive is only as great as its potential to ensure the participation of its fastest-growing demographic groups. Latinos, African Americans, and other students of color represent America's untapped STEM talent pool, as do women in the important fields of engineering and computer science. Diversity policies and programs on two- and four-year campuses are necessary to ensure that more underrepresented students pursue STEM majors and graduate with STEM credentials. This will require higher-education institutions to collaborate in new ways, as well as an influx of resources for K–12 outreach and the participation of faculty in such efforts.

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A new framework calls for K–12 classrooms that bring science and engineering alive for students.

A Framework for K–12 Science Education

Looking Toward the Future of Science Education

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It is an exciting time for K–12 science and engineering education in the United States; a new vision for teaching science and engineering promises to transform the experiences of students in all grades across the country. This vision, articulated in a new report from the National Research Council (NRC), calls for classrooms that bring science and engineering alive for students, emphasizing the satisfaction of pursuing compelling questions and the joy of discovery and invention. *A Framework for K–12 Science Education* (NRC 2012) provides a blueprint for new state standards in science education. Based on this framework a consortium of educators and scientists from

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26 states is developing Next Generation Science Standards, which will be available in April 2013 for states to use in guiding what students learn in science for the next decade or more.

In this article we provide an overview of the framework and briefly describe its development process. Our goal is to help readers become familiar with the framework, understand how it differs from existing standards, and appreciate its potential for transforming science and engineering education in K–12. We end by emphasizing that the framework alone will not lead to the changes envisioned. For those to occur, all stakeholders in science and engineering education must work in concert toward this new vision.

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Introduction

The framework was developed under the auspices of the NRC Board on Science Education (BOSE) in collaboration with the National Academy of Engineering and the National Academies' Teacher Advisory Council. BOSE focuses on science education for all ages, in school settings and across many venues outside of school such as museums, nature centers, zoos, after-school programs, and community organizations. The Board convenes experts who draw on their professional knowledge and examine research on learning and teaching to make recommendations about how to improve science education.

The impetus for the framework and the anticipated standards was the convergence of three main factors. First, there has been persistent and growing concern that current approaches to K–12 science education have not in general successfully prepared students to live in an increasingly technological world or compete for jobs in science, technology, and engineering. Second, in the nearly two decades since the previous science standards

were released, much has been learned about how people learn science and about how to improve instruction. Finally, the momentum toward common standards in mathematics and English/language arts suggested that there was an opportunity for a similar set of standards in science.

Recognizing these convergent factors, the Carnegie Corporation of New York provided funding for a two-stage process of standards development. In the first stage the NRC developed the *framework*; in the second stage, now under way, a consortium of 26 states coordinated by Achieve, Inc. (a nonprofit education policy organization) is developing *standards* that provide more detailed specification of what students should know and be able to do at each grade. All of the work has involved a partnership of four key organizations—the NRC, Achieve, the American Association for the Advancement of Science (AAAS), and the National Science Teachers Association (NSTA)—as well as input from the broader science and science education communities.

A New Vision for Science and Engineering in K–12

The framework is designed to help realize a vision for education in the sciences and engineering in which students, over multiple years, actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields. (NRC 2012, pp. 8–9)

Although state standards for K–12 science education have existed since the mid-1990s, the new framework incorporates several innovations that represent significant advances in approaches to learning and teaching. First, science and engineering consist of both knowing and doing; simply memorizing discrete facts or the steps in a design process does not lead to deep understanding and development of flexible skills. Instead, the practices of science and engineering—what scientists and engineers actually do—must have a central place in science classrooms. Second, the framework focuses on a set of core ideas investigated in increasing depth over multiple years of schooling as well as crosscutting concepts that are important across science and engineering disciplines. The progression of learning and teaching can start in the earliest grades and is built in a coherent way over a student's academic career. Finally, engineering is more fully integrated into the framework than in previous science standards, expanding students' understanding of applications of science and how science and

engineering are linked. These innovations are described in the sections below.

Unfortunately, at present many K–12 students do not have access to opportunities that allow them to experience science and engineering as envisioned in the framework (NRC 2007; Schmidt and McKnight 2012). This problem is particularly acute for students in schools that enroll higher concentrations of non-Asian minority students and for students in high-poverty schools (NRC 2006a; Weiss et al. 2003). The vision of the framework takes on this problem of access, emphasizing that *all* students can learn science and engineering and should have opportunities to engage in the full range of science and engineering practices.

The overarching goal of the framework is to ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science and engineering; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are informed consumers of scientific and technological information related to their everyday lives; can continue to learn about science and engineering outside school; and have the skills to enter careers of their choice, especially in science, engineering, and technology.

Grounded in Evidence

The framework is based on a rich and growing body of research on teaching and learning as well as nearly two decades of efforts to define foundational knowledge and skills for K–12 science and engineering. The NRC committee members—learning scientists, educational researchers, or educational policymakers or practitioners—were charged with identifying the scientific and engineering ideas and practices that are most important for K–12 students to learn.

The committee's deliberations were informed by the work of four design teams, each focused on major disciplines in science and engineering: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science. The committee and design teams reviewed evidence including research on learning and teaching in science and engineering, national-level documents that provide guidance on what students should know in science and engineering, and evaluations of previous standards efforts. They also carefully considered NRC reports published over the last decade. Research on how children learn science and the implications for science instruction in grades

K–8 was central to *Taking Science to School: Learning and Teaching Science in Grades K–8* (NRC 2007). *America's Lab Report: Investigations in High School Science* (NRC 2006a) examined the role of laboratory experiences in high school science instruction, and *Learning Science in Informal Environments* (NRC 2009) focused on the role of science learning experiences outside school. Complementing these publications, *Systems for State Science Assessment* (NRC 2006b) studied large-scale assessments of science learning, and *Engineering in K–12 Education* (NAE and NRC 2009) explored the knowledge and skills needed to introduce K–12 students to engineering.

The framework also builds on the two previous standards documents for science—*Benchmarks for Scientific Literacy* (AAAS 1993) and *National Science Education Standards* (NRC 1996)—as well as *Standards for Technological Literacy: Content for the Study of Technology* (ITEEA 2000). Finally, the committee examined more recent efforts: the *Science Framework for the 2009 National Assessment of Educational Progress* (NAEP 2009), *Science College Board Standards for College Success* (College Board 2009), NSTA's Science Anchors project (NSTA 2009), and a variety of state and international science standards and curriculum specifications.

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The Structure of the Framework

The committee concluded that K–12 science and engineering education should support the integration of knowledge and practice, focus on a limited number of disciplinary core ideas and crosscutting concepts, and be designed so that students continually build on and revise their knowledge and abilities through the years. In support of these aims, the framework consists of a limited number of elements in three dimensions: (1) scientific and engineering practices, (2) crosscutting concepts, and (3) disciplinary core ideas in science and engineering (see Box 1). To support learning all three dimensions need to be integrated in standards,

BOX 1

Messages Tested in the Online Survey

1. Scientific and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

2. Crosscutting Concepts

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

3. Disciplinary Core Ideas

Physical Sciences

- PS 1: Matter and its interactions
- PS 2: Motion and stability: Forces and interactions
- PS 3: Energy
- PS 4: Waves and their applications in technologies for information transfer

Life Sciences

- LS 1: From molecules to organisms: Structures and processes
- LS 2: Ecosystems: Interactions, energy, and dynamics
- LS 3: Heredity: Inheritance and variation of traits
- LS 4: Biological evolution: Unity and diversity

Earth and Space Sciences

- ESS 1: Earth's place in the universe
- ESS 2: Earth's systems
- ESS 3: Earth and human activity

Engineering, Technology, and the Applications of Science

- ETS 1: Engineering design
- ETS 2: Links among engineering, technology, science, and society

Source: NRC (2012).

curricula, instruction, and assessment and should be developed across grades K–12.

Dimension 1: Scientific and Engineering Practices

Dimension 1 focuses on important practices used by scientists and engineers, such as modeling, developing explanations or solutions, and engaging in argumentation. Engaging in the full range of scientific practices helps students understand how scientific knowledge develops and gives them an appreciation of the wide range of approaches to investigate, model, and explain the world. Similarly, engaging in the practices of engineering helps students understand the work of engineers and the links between engineering and science. It also provides opportunities for students to apply their scientific knowledge.

Research shows that students best understand scientific ideas and engineering design when they actively use their knowledge while engaging in the practices. A major goal of the framework is to shift the emphasis in science education from teaching detailed facts to

immersing students in doing science and engineering and understanding the big picture ideas. This might look different in 2nd grade, 8th grade, and 10th grade, but at all levels students have the capacity to think scientifically and engage in the practices.

By engaging in and reflecting on the full range of science and engineering practices, students develop their understanding of not only the topic at hand but also both the nature of science and the rigorous process by which the scientific community comes to accept one explanation as better than another in describing a phenomenon. Likewise they learn how engineers apply similarly rigorous analysis in a systematic way in developing, testing, and revising designs for solutions to problems.

Dimension 2: Crosscutting Concepts

Dimension 2 defines seven key crosscutting concepts for science and engineering. These concepts provide students with ways to connect knowledge from the various disciplines into a coherent and scientific view of

the world. They are not unique to the framework but echo many of the unifying concepts and processes in the *National Science Education Standards* (NRC 1996), the common themes in the *Benchmarks for Science Literacy* (AAAS 1993), and the unifying concepts in the *Science College Board Standards for College Success* (College Board 2009).

Students' understanding of these crosscutting concepts should be reinforced by their repeated use in instruction across the disciplinary core ideas (see Dimension 3 below). For example, the concept of "cause and effect" could be discussed in the context of plant growth in a biology class and in the context of study of the motion of objects in a physics class. Throughout their science and engineering education, students should learn about the crosscutting concepts in ways that illustrate their applicability across all of the core ideas.

Dimension 3: Disciplinary Core Ideas

Dimension 3 describes disciplinary core ideas for the physical sciences, life sciences, and earth and space sciences because these disciplines are typically included in K–12 science education. Engineering, technology, and applications of science are featured alongside these disciplines for three critical reasons: to reflect the importance of understanding the human-built world, to stress the applications of science in the lives of students, and to integrate the teaching and learning of science, engineering, and technology and thus demonstrate their value for learning both science and engineering design.

In developing the core ideas the committee sought both to limit the number of discrete ideas included and to illustrate the rich, conceptual nature of explanations in science. The goal is to avoid superficial coverage of multiple disconnected topics (sometimes referred to as the "mile-wide and inch-deep" curriculum; Schmidt et al. 1997). The focus on a limited number of core ideas is designed to allow for deep exploration of important concepts as well as time for students to develop meaningful understanding, to actually practice science and engineering, and to reflect on their nature.

Supporting Learning over Time

Research on learning shows that to develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to engage in the practices and work with the underlying ideas and to appreciate the interconnections among those ideas over a period of years rather than weeks or months

(NRC 2007). This notion of a systematic sequence for learning over time is often called a learning progression (CPRE 2009; NRC 2007; Smith et al. 2006), and it describes both how students' understanding of an idea matures over time and what instructional supports and experiences are needed for students to make progress. The design of the framework is intended to support this kind of coherence across grades. Thus, in addition to explaining the core and component ideas, the committee described which aspects of each core idea should be learned by the end of grades 2, 5, 8, and 12.

Importantly, these progressions begin in the earliest grades. Research on young children's learning reveals that, from all backgrounds and socioeconomic levels, they have a surprising amount of knowledge of the world, their knowledge is well organized, and they reason about it in sophisticated ways (Carey 1985; Gelman and Baillargeon 1983; Gelman and Kalish 2005; Metz 1995). Thus, before they even enter school children have developed their own ideas about the physical, biological, and social worlds and how they work. By listening to and taking these ideas seriously, educators can build on what children already know and can do.

The implication of these findings for the framework is that building progressively more complex explanations of natural phenomena should be central throughout K–5, as opposed to focusing only on description in the early grades and leaving explanation to the later grades. Similarly, students can engage in scientific and engineering practices beginning in the earliest grades.

Before they even enter school children have developed their own ideas about the physical, biological, and social worlds and how they work.

Integrating Engineering

As noted, one of the major innovations of the framework is the integration of engineering across all three dimensions. Engineering and technology were included in previous national standards, but at the state level either science standards do not include them or they are not implemented in the classroom. Although most

states have adopted the *Standards for Technological Literacy* (ITEEA 2000), the teacher corps for delivering this content is an order of magnitude smaller than that for science. The integration of engineering in the framework is intended to address this deficit.

Emphasizing connections between science, engineering, and technology makes sense from the perspective of the disciplines as well as from a learning perspective. From a disciplinary perspective the fields are mutually supportive. New technologies expand the reach of science, allowing the study of realms previously inaccessible to investigation; scientists depend on the work of engineers to produce the instruments and computational tools they need to conduct research. Engineers in turn depend on the work of scientists to understand how different technologies work so they can be improved; scientific discoveries can be exploited to create new technologies. Scientists and engineers often work together in teams, especially in new fields, such as nanotechnology or synthetic biology, that blur the lines between science and engineering.

K–12 students should understand the links among engineering, technology, science, and society, and at increasing levels of sophistication as they mature.

From a learning perspective there are multiple reasons for including engineering in the science framework. First, it is important for students to explore the practical use of science, given that a singular focus on the core ideas of the disciplines would tend to short-change the importance of applications. Second, at least at the K–8 level, topics related to engineering and technology typically do not appear elsewhere in the curriculum and thus are neglected if not included in science instruction. Finally, engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science—and, for many, their interest in

science—as they recognize the interplay among science, engineering, and technology.

Engineering is reflected in the practices as well as through two disciplinary core ideas. The first concerns the knowledge needed to engage effectively in engineering design. Although there is not yet broad agreement on the full set of core ideas in engineering (NAE 2010) there is emerging consensus that design is a central practice of engineering; indeed, it is the focus of the vast majority of K–12 engineering curricula currently in use (NAE 2010).

The second idea calls for students to explore the links among engineering, technology, science, and society. Students should understand these connections, and at increasing levels of sophistication as they mature.

The goal of including ideas related to engineering, technology, and the applications of science in the framework for science education is not to replace current K–12 engineering and technology courses. Rather, it is to strengthen science education by helping students understand the similarities and differences between science and engineering and by making the connections between them explicit.

Next Steps

While the *Framework* report provides important guidance for improving K–12 science education, it is only the first step in what must be a sustained, multipronged effort over the next several years.

The Next Generation Science Standards

The development of the Next Generation Science Standards (NGSS) is already under way. Using the practices, crosscutting concepts, and core ideas that the NRC report lays out, 26 states, coordinated by Achieve, are developing standards for what students should learn at different grade levels. The writing team for the NGSS includes members, many of them K–12 educators, with wide-ranging expertise—in elementary, middle, and high school science, students with disabilities, English language acquisition, state-level standards and assessment, and workforce development. Additional review and guidance are provided by advisory committees composed of nationally recognized leaders in science and science education as well as business and industry.

Outreach and Broad Involvement of Stakeholders

As part of the development process, two drafts of the standards undergo multiple reviews from many

stakeholders, allowing all who have a stake in science education an opportunity to inform the development of the standards. The first public draft was released for comment in May 2012 and the second in January 2013.

Previous efforts have shown that the standards alone will not produce the transformations in classrooms and schools that are necessary to achieve the vision of the framework. Numerous changes will be required at all levels of the K–12 education system, including changes to curriculum, instruction, assessment, and professional development for teachers. Such changes will necessarily involve multiple stakeholders working toward common goals with the same vision in mind. The *Framework* report includes a chapter outlining the work needed.

This work has already begun. The Board on Science Education has undertaken outreach to curriculum developers and assessment designers; educators who train teachers and create professional development materials for them; and state and district science supervisors, who make key decisions about curriculum, instruction, and professional development. Project partners NSTA, Achieve, and AAAS are also working to lay the groundwork for implementing the standards.

There are also important efforts under way at the state level to prepare for implementation. Achieve is helping states develop implementation plans and think through the kinds of support and resources that will be needed. Reaching beyond the collaborating states, the Council of State Science Supervisors has initiated the Building Capacity for State Science Education (BCSSE) project, engaging teams in 43 states in efforts to understand the framework, the NGSS, and the challenges inherent in implementation.

As states, districts, and individual schools undertake the work of adopting and implementing the NGSS they will need support from scientists and engineers, who will need to become familiar with the vision and language of the framework and, as they recognize the power of this vision for improving science education, align both their advocacy efforts in education and their direct work in schools with it. Their work could include both political support for state-level adoption of NGSS and support to local schools and districts that are seeking help in providing appropriate professional development for teachers.

Teacher Preparation

Implementation of the framework and NGSS will require rethinking science teacher preparation: those

who plan to teach science and engineering practices will need opportunities to engage in them as they learn. For both new and experienced teachers, research or engineering internships during the summer can provide such an opportunity, which can be enhanced when scientist or engineer mentors relate the work to the practices described in the framework.

Conclusion

Science, engineering, and the technologies they influence permeate every aspect of modern life, and some knowledge of them is required to understand major public policy issues and to make informed everyday decisions. The framework and NGSS represent the best opportunity available to engage students in science and engineering in ways that will not only help them see how these fields are instrumental in addressing major challenges that confront society but also inspire some to pursue careers in science, engineering, or technology.

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NAE News and Notes

Class of 2013 Elected

In February, NAE elected 69 new members and 11 foreign associates, bringing the total US membership to 2,250 and the number of foreign associates to 211. Academy membership honors those who have made outstanding contributions to “engineering research, practice, or education, including, where appropriate, significant contributions to the engineering literature,” and to the “pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education.” A list of newly elected members and foreign associates follows, with their primary affiliations at the time of election and a brief statement of their principal engineering accomplishments.

Paul R. Adams, chief operating officer, Pratt & Whitney, East Hartford, Connecticut. For leadership and innovation for gas turbine engines, especially the Geared Turbofan.

Anant Agarwal, president, edX (online learning initiative of MIT and Harvard University), and professor, Electrical Engineering and Computer Science Department, Massachusetts Institute of Technology, Cambridge. For contributions to shared-memory and multicore computer architectures.

James M. Anderson, Distinguished University Professor, and professor of pathology, macromolecular science, and biomedical engineering, Case Western Reserve University, Cleveland, Ohio. For

contributions to understanding tissue/biomaterials interactions for designing and testing medical devices.

Peter Louis Andresen, principal scientist, ceramics and metallurgy, Corrosion and Electrochemistry Laboratory, GE Global Research Center, Schenectady, New York. For prediction and prevention of stress corrosion cracking in nuclear materials.

Joseph J. Beaman Jr., Earnest F. Gloyne Regents Chair in Engineering, Mechanical Engineering Department, University of Texas, Austin. For innovation, development, and commercialization of solid freeform fabrication and selective laser sintering.

Murty P. Bhavaraju, senior consultant, PJM Interconnection, Norristown, Pennsylvania. For probabilistic reliability evaluation tools for large electric power systems.

Lorenz T. Biegler, Bayer Professor of Chemical Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania. For contributions in large-scale nonlinear optimization theory and algorithms for application to process optimization, design, and control.

Donna G. Blackmond, professor of chemistry, Scripps Research Institute, La Jolla, California. For kinetic and mechanistic studies of catalytic organic reactions for pharmaceuticals, and for studies of chiral amplification.

Dawn A. Bonnell, Trustees Chair Professor of Materials Science, and director, Nano-Bio Interface Cen-

ter, University of Pennsylvania, Philadelphia. For development of atomic-resolution surface probes, and for institutional leadership in nanoscience.

Craig T. Bowman, professor of mechanical engineering, Stanford University, Stanford, California. For contributions to understanding pollutant formation processes in combustion systems to reduce harmful emissions.

Ursula M. Burns, chairman of the board and chief executive officer, Xerox Corp., Norwalk, Connecticut. For technical and business leadership of the renaissance of a global services and technology company.

Robert S. Chau, Intel Senior Fellow and director of transistor research and nanotechnology, Technology and Manufacturing Group, Intel Corp., Hillsboro, Oregon. For contributions to CMOS transistor technologies for advanced logic products.

Weng Cho Chew, professor, Department of Electrical and Computer Engineering, University of Illinois, Urbana. For contributions to large-scale computational electromagnetics of complex structures.

Steven Lee Crouch, Theodore W. Bennett Chair in Mining Engineering and Rock Mechanics, and dean, College of Science and Engineering, University of Minnesota, Minneapolis. For contributions to simulation methodology for the behavior of fractured rock masses.

Thomas F. Degnan Jr., manager, breakthrough and leads generation,

ExxonMobil Research and Engineering Co., Annandale, New Jersey. For contributions to novel catalytic processes for improved lubricant, fuel, and petrochemical production.

Gregory G. Deierlein, professor, Department of Civil and Environmental Engineering, and John A. Blume Professor in the School of Engineering, Stanford University, Stanford, California. For development of advanced structural analysis and design techniques and their implementation in design codes.

David L. Dill, professor, Department of Computer Science, Stanford University, Stanford, California. For the development of techniques to verify hardware, software, and electronic voting systems.

David A. Dornfeld, Will C. Hall Family Chair in Engineering, and professor of mechanical engineering, University of California, Berkeley. For contributions to sustainability in advanced manufacturing, sensors, and precision material processing.

Abbas El Gamal, Hitachi America Professor in the School of Engineering, and professor and chair, Department of Electrical Engineering, Stanford University, Stanford, California. For contributions in information theory, information technology, and image sensors.

James O. Ellis Jr., retired president and chief executive officer, Institute of Nuclear Power Operations, Atlanta, Georgia. For leadership in advancing safe nuclear power plant operations throughout the world.

Charbel H. Farhat, Vivian Hoff Professor of Aircraft Structures, and chairman, Department of Aeronautics and Astronautics, Stanford University, Stanford, California. For contributions to

computing fluid-structure interactions and their applications in aeronautical, naval, and mechanical engineering.

Edward W. Felten, professor of computer science and public affairs, and director, Center for Information Technology Policy, Princeton University, Princeton, New Jersey. For contributions to security of computer systems, and for impact on public policy.

Eric R. Fossum, professor of engineering, Dartmouth College, Hanover, New Hampshire. For inventing and developing the CMOS active-pixel image sensor and camera-on-a-chip.

Curtis W. Frank, William M. Keck Sr. Professor of Chemical Engineering, Stanford University, Stanford, California. For elucidation of molecular organization in polymers and other soft materials.

Ashok J. Gadgil, director and senior scientist, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, and Andrew and Virginia Rudd Family Foundation Professor of Safe Water and Sanitation, University of California, Berkeley. For engineering solutions to the problems of potable water and energy in underdeveloped nations.

Charles F. Gay, president, Applied Solar Division, Applied Materials Inc., Santa Clara, California. For leadership in the development of the global photovoltaic industry.

David Goodyear, senior vice president and chief bridge engineer for North American Operations, T.Y. Lin International Group, Olympia, Washington. For leadership in concrete segmental, cable-stayed, and hybrid bridge design and construction.

Helen Greiner, chief executive officer and founder, CyPhy Works Inc., Danvers, Massachusetts. For leadership in the design, development, and application of practical robots.

David H. Gustafson, professor of industrial and systems engineering and preventive medicine, University of Wisconsin, Madison. For industrial and systems engineering methods to improve the care of aging, lung cancer, severe asthma, and drug addiction patients.

R. John Hansman Jr., T. Wilson Professor of Aeronautics and Astronautics and Engineering Systems, and director, International Center for Air Transportation, Massachusetts Institute of Technology, Cambridge. For development of aviation display and alerting systems for air safety.

Eliyahou (Eli) Harari, co-founder, retired chairman, and chief executive officer, SanDisk Corp., Saratoga, California. For technology advances of commercial flash memory systems.

Joseph P. Heremans, Ohio Eminent Scholar, professor of mechanical and aerospace engineering, and professor of physics, Ohio State University, Columbus. For discoveries in thermal energy transfer and conversion to electricity, and for commercial devices employed in automobiles.

Maurice Herlihy, professor of computer science, Brown University, Providence, Rhode Island. For concurrent computing techniques for linearizability, nonblocking data structures, and transactional memory.

Eric Horvitz, distinguished scientist and managing co-director, Microsoft Research, Redmond, Washington. For computational

mechanisms for decision making under uncertainty and with bounded resources.

John Rossman Huff, chairman, Oceaneering International Inc., Houston, Texas. For contributions to the development of remotely operated vehicles for deep-water oil and gas operations.

Ganesh Kailasam, research and development vice president and global research and development director, Performance Materials Division, Dow Chemical Co., Freeport, Texas. For development of processes for production of high-performance polymers including polyetherimides.

Edward Kavazanjian Jr., senior sustainability scientist, Global Institute of Sustainability, and professor, School of Sustainable Engineering and the Built Environment, Ira A. Fulton School of Engineering, Arizona State University, Tempe. For geotechnical engineering for municipal solid-waste management, earthquake hazard mitigation, and safety of transportation facilities.

John E. Kelly III, senior vice president and director of IBM Research, IBM Corp., Yorktown Heights, New York. For contributions to the US semiconductor industry through technology innovations and strategic leadership.

Carl C. Koch, Kobe Steel Distinguished Professor of Materials Science and Engineering, North Carolina State University, Raleigh. For synthesis of amorphous and nanocrystalline alloys by mechanical attrition.

Charles E. Kolb, president and chief executive officer, Aerodyne Research Inc., Billerica, Massachusetts. For instruments that advanced measurements of air pollution and aerosols.

Vijay Kumar, UPS Foundation Professor, School of Engineering and Applied Sciences, University of Pennsylvania, Philadelphia. For contributions in cooperative robotics, networked vehicles, and unmanned aerial vehicles, and for leadership in robotics research and education.

Enrique J. Lavernia, dean, College of Engineering, and Distinguished Professor of Chemical Engineering and Materials Science, University of California, Davis. For contributions to novel processing of metals and alloys, and for leadership in engineering education.

Raphael C. Lee, Paul S. and Allene T. Russell Professor of Surgery, Medicine, Organismal Biology and Anatomy, University of Chicago, Illinois. For contributions to understanding cell injury associated with trauma including electrical shock and thermal burns.

Kam W. Leong, James B. Duke Professor of Biomedical Engineering, Pratt School of Engineering, Duke University, Durham, North Carolina. For contributions to engineered drug delivery and non-viral-mediated gene delivery.

James C. Liao, Ralph M. Parsons Foundation Chair Professor, Department of Chemical and Biomolecular Engineering, University of California, Los Angeles. For advances in metabolic engineering of microorganisms to produce fuels and chemicals.

Bruce E. Logan, Evan Pugh Professor and Kappe Professor of Environmental Engineering, Pennsylvania State University, University Park. For microbial electrochemical technologies for wastewater treatment and sustainable energy generation.

Gerald H. Luttrell, A.T. Massey Coal Company Professor of Mining

and Minerals Engineering, Virginia Polytechnic Institute and State University, Blacksburg. For advancing separation technologies for the mineral and coal industries.

Edward Wilson Merrill, professor emeritus, Department of Chemical Engineering, Massachusetts Institute of Technology. For contributions to biocompatible materials, biorheology, and biomedical engineering education.

Arthur L. Money, independent consultant, Alexandria, Virginia. For engineering developments and technical leadership in support of US national security efforts.

John A. Montgomery, director of research, US Naval Research Laboratory, Washington, DC. For leading the Navy's electronics-warfare technical authority, and for developing critical operational systems.

José M.F. Moura, University Professor, Department of Electrical and Computer Engineering, and director, Information and Communications Technologies Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania. For contributions to the theory and practice of statistical signal processing.

Richard M. Murray, Thomas E. and Doris Everhart Professor of Control and Dynamical Systems and Bioengineering, California Institute of Technology, Pasadena. For contributions in control theory and networked control systems with applications to aerospace engineering, robotics, and autonomy.

M. Allen Northrup, principal, Northrup Consulting Group, San Francisco, California. For miniaturization and commercialization of gene amplification and immunosensor technology.

Michael Ortiz, Dotty and Dick Hayman Professor of Aeronau-

tics and Mechanical Engineering, California Institute of Technology, Pasadena. For contributions to computational mechanics to advance the underpinnings of solid mechanics.

Thomas J. Overbye, Fox Family Professor in Electrical and Computer Engineering, University of Illinois, Urbana-Champaign. For the integration of visualization and analysis tools for power systems.

Robin Podmore, president, Inc-Sys Inc., Bellevue, Washington. For development of modeling and simulation tools for power system operation.

Stephen R. Quake, Lee Otterson Professor of Bioengineering and Applied Physics, and co-chair, Department of Bioengineering, Stanford University, Stanford, California. For achievements in single-cell analysis and large-scale integration of microfluidic devices.

Robert E. Schafrik, general manager of materials and process engineering, GE Aviation, Cincinnati, Ohio. For innovation in materials for gas turbine engines.

Jan C. Schilling, advanced products chief engineer, GE Aviation, Cincinnati, Ohio. For advancing technology for modern turbofan engines.

Bal Raj Sehgal, Emeritus Professor of Nuclear Power Safety, Royal Institute of Technology, Stockholm, Sweden. For contributions to predicting accident behavior of nuclear reactor systems.

Eric S.G. Shaqfeh, Lester Levi Carter Professor and chair, Department of Chemical Engineering, and professor of mechanical engineering, Stanford University, Stanford, California. For contributions to dynamics and rheology of complex fluids,

including polymeric liquids, vesicles, and fiber suspensions.

Pradeep S. Sindhu, vice chairman, chief technical officer, and founder, Juniper Networks, Sunnyvale, California. For contributions to technology and commercialization of Internet Protocol routing.

Krishna (Kris) P. Singh, president and chief executive officer, Holtec International, Marlton, New Jersey. For engineering and business leadership for increased power plant efficiency and improved safety of spent nuclear fuel storage worldwide.

William A. Thornton, corporate consultant, Cives Engineering Corp., Roswell, Georgia. For rational methods of designing steel connections, and for leadership in steel building design.

Rex W. Tillerson, chairman and chief executive officer, ExxonMobil Corp., Irving, Texas. For engineering leadership in the production of hydrocarbons in remote and hostile environments.

John J. Tracy, chief technology officer and senior vice president of engineering, operations and technology, Boeing Co., Chicago, Illinois. For leadership in advanced composites design and manufacturing technology for air and space vehicles.

Sharon L. Wood, Robert L. Parker Sr. Centennial Professor and chair, Department of Civil, Architectural, and Environmental Engineering, University of Texas, Austin. For design of reinforced concrete structures and associated seismic instrumentation for extreme loadings and environments.

Ken Xie, founder, president, and chief executive officer, Fortinet Inc., Sunnyvale, California. For contributions to cybersecurity,

including network security systems and services.

Elias Zerhouni, president, global research and development, Sanofi, Pasadena, Maryland. For noninvasive MRI methods for complex tissues, and for national leadership in translational medical research.

New Foreign Associates

John A. Cherry, adjunct professor in the School of Engineering, and director, University Consortium for Field-Focused Groundwater Contamination Research, University of Guelph, Ontario, Canada. For contributions to understanding contaminant migration and development of engineered systems for groundwater remediation.

Richard Henry Friend, Cavendish Professor of Physics, University of Cambridge, United Kingdom. For contributions to science, engineering, and commercialization of organic polymer semiconductor devices.

H. David Hibbitt, founder and retired chairman, ABAQUS Inc. (now known as Dassault Systèmes Simulia Corp.), Bristol, Rhode Island. For creation and development of the ABAQUS finite element code for nonlinear structural analysis and its worldwide dissemination.

Urs Hölzle, Google Fellow and senior vice president for technical infrastructure, Google Inc., Mountain View, California. For contributions to the design, operation, and energy efficiency of large-scale data centers.

Jens Rasmussen, emeritus professor, Risø National Laboratory, Roskilde, and Technical University of Copenhagen, Smørum, Denmark. For contributions to the science and engineering of human error and

reliability, and for the modeling of human behavior.

Shlomo Shamai (Shitz), William Fondiller Chair in Telecommunications, Department of Electrical Engineering, Technion-Israel Institute of Technology, Haifa. For contributions to information theory for wireless communication technology.

Ratan N. Tata, chairman emeritus, Tata Group, Mumbai, India. For outstanding contributions to industrial development in India and the world.

Henrik Topsøe, executive vice president and chief scientific officer, Haldor Topsøe A/S, Lyngby, Denmark. For development of hydrodesulfurization catalysts and elucidation of their active sites.

Mathias Uhlen, professor of microbiology, Department of Biotechnology, and director, Science for Life Laboratory, Royal Institute of Technology, Stockholm, Sweden. For invention and commercialization of proteinA chromatography,

HT DNA sequencing, and the Human Protein Atlas.

KeChang Xie, vice president, Chinese Academy of Engineering, Beijing. For understanding coal molecular structure and its reactivity, and for leadership in the modern clean coal conversion industry.

Ji Zhou, president, Chinese Academy of Engineering, Beijing. For research contributions in numeric control, computer-aided design, and design optimization.

NAE Members Receive Three National Medals of Science and Four National Medals of Technology and Innovation

On February 1, 2013, at a ceremony in the East Room of the White House, President Barack Obama presented the 2012 National Medals of Science and National Medals of Technology and Innovation. In announcing the laureates, he said: "I am proud to honor these inspiring American innovators. They represent the ingenuity and imagination that have long made this nation great—and they remind us of the enormous impact a few good ideas can have when these creative qualities are unleashed in an entrepreneurial environment." Seven NAE

members were among the recipients of these prestigious awards.

NAE members **Solomon Golomb**, **John Goodenough**, and **Leroy Hood** received the National Medal of Science.

Solomon Golomb, Andrew and Erna Viterbi Professor of Communications and Distinguished University Professor, University of Southern California, received the award for "pioneering work in shift register sequences that changed the course of communications from analog to digital, and for numerous innovations in reliable and secure space,

radar, cellular, wireless, and spread-spectrum communications."

John Goodenough, Centennial Professor of Engineering, Texas Materials Institute, University of Texas at Austin, was honored for "groundbreaking cathode research that led to the first commercial lithium ion battery, which has since revolutionized consumer electronics with technical applications for portable and stationary power."

Leroy Hood, president, Institute for Systems Biology, was cited for "pioneering spirit, passion, vision, inventions, and leadership combined



Solomon Golomb, National Medal of Science Laureate



John Goodenough, National Medal of Science Laureate



Leroy Hood, National Medal of Science Laureate

with unique cross-disciplinary approaches resulting in entrepreneurial ventures, transformative commercial products and several new scientific disciplines that have challenged and transformed the fields of biotechnology, genomics, proteomics, personalized medicine, and science education.”

National Medals of Technology and Innovation were presented to four NAE members: **Frances Arnold**, **Robert Langer**, **Art Rosenfeld**, and **Rangaswamy Srinivasan**.

Frances Arnold, Dick and Barbara Dickinson Professor of Chemical Engineering, Bioengineering, and Biochemistry, California Institute of Technology, was honored for “pioneering research on biofuels and chemicals that could lead to the replacement of pollution-generating materials.”

Robert Langer, David H. Koch Institute Professor, Massachusetts Institute of Technology, was cited for “inventions and discoveries that led to the development of controlled drug release systems, engineered tissues, angiogenesis inhibitors, and new biomaterials.”

Art Rosenfeld, Distinguished Scientist Emeritus, EO Lawrence Berkeley National Laboratory, received the award for “extraordi-



Frances Arnold, National Medal of Technology and Innovation Laureate



Robert Langer, National Medal of Technology and Innovation Laureate



Art Rosenfeld, National Medal of Technology and Innovation Laureate



Rangaswamy Srinivasan, National Medal of Technology and Innovation Laureate

nary leadership in the development of energy-efficient building technologies and related standards and policies.”

Rangaswamy Srinivasan, president, UVTech Associates, together with Samuel Blum and James Wynne, was recognized for “the

pioneering discovery of excimer laser ablative photodecomposition of human and animal tissue, laying the foundation for PRK and LASIK laser refractive surgical techniques that have revolutionized vision enhancement.”

NAE Newsmakers

Alice M. Agogino, Roscoe and Elizabeth Hughes Professor of Mechanical Engineering, University of California, Berkeley, received the 2012 American Association for the Advancement of Science (AAAS) **Mentor Award for Lifetime Achievement** during a ceremony held on February 15 at the 2013 AAAS Annual Meeting in

Boston, Massachusetts. Dr. Agogino has been honored by AAAS for her efforts to significantly increase the number of women and African- and Hispanic-American doctorates in mechanical engineering. Through her mentoring, example, and interactions, Dr. Agogino has inspired a large number of students and junior faculty members to include

the scholarship of teaching as part of their research portfolios. During her career, she has mentored 23 doctoral students (17 from minority backgrounds), 82 master’s students (36 minority), and an estimated 800 undergraduate researchers.

James J. Coleman, professor, Department of Electrical and Computer Engineering, University of

Illinois at Urbana-Champaign, is the recipient of the **2013 John Tyndall Award** presented by The Optical Society. Professor Coleman is being recognized for “contributions to semiconductor lasers and photonic materials, processing and device designs, including high reliability strained-layer lasers.” He will be presented the award during the plenary session of the 2013 Optical Fiber Communication Conference and Exposition/National Fiber Optic Engineers Conference taking place at the Anaheim Convention Center, March 17–21.

Stuart Cooper, University Scholar Professor, Department of Chemical and Biomolecular Engineering, The Ohio State University, was selected for the **Chemistry of Thermoplastic Elastomers Award** sponsored by the Ralph S. Graft Foundation and presented by the American Chemical Society Rubber Division. The award was established in 1991 as a part of the Rubber Division’s continuing effort to recognize significant contributions of scientists in the advancement of the chemistry of thermoplastic elastomers. Particular emphasis is placed on innovations that have yielded significant new commercial or patentable materials. The award will be presented during the Rubber Division’s 183rd Spring Technical Meeting, April 22–24, 2013, in Akron, Ohio.

The US Air Force Academy has selected **Natalie W. Crawford**, Senior Fellow, The RAND Corporation, as the latest recipient of its **Thomas D. White National Defense Award**. The Award is presented annually to a US citizen who has contributed significantly to US national defense. Mrs. Crawford has been a long-term supporter of the Air Force Academy and was instru-

mental in establishing an important long-term relationship between RAND and the Academy. A plaque is displayed in the USAF Academy’s Arnold Hall with the names of annual winners, who in past years have included Bob Hope, Sen. Barry Goldwater, Dr. Condoleezza Rice, and Sen. John Glenn.

The Siemens Foundation has named **John P. Holdren**, assistant to the president for science and technology and director of the White House Office of Science and Technology Policy, the recipient of its **2012 Siemens Foundation Founder’s Award**. The annual award recognizes outstanding individuals for encouraging students to engage in STEM subjects. “The Siemens Foundation is honored to recognize Dr. Holdren for his outstanding efforts to increase student engagement in science, technology, engineering and mathematics,” said Thomas N. McCausland, chairman of the board, Siemens Foundation. “His contributions through such initiatives as the White House Science Fair have sent a strong signal to students, parents and teachers nationwide that participating in STEM subjects is a worthwhile and rewarding endeavor.”

Ahsan Kareem, Robert M. Moran Professor of Civil and Engineering and Geological Sciences, University of Notre Dame, has been named an **honorary member of the Japan Association for Wind Engineering (JAWE)**. There are only three international honorary members in the JAWE. Dr. Kareem is the first from the United States and one of only a few researchers whose work has transformed his field through a continued series of innovations. Over the years he has been acknowledged for his eminence in the field of wind

engineering, structural engineering and engineering mechanics; and for profound contributions to the knowledge base with immediate applications, e.g., American Society of Civil Engineers Standard of Wind Loads and for development of Web-based analysis and tools for design practice.

Bernard L. Koff, independent consultant, has been named the winner of the Society of Automotive Engineers (SAE) **2012 Cliff Garrett Award**. The award recognizes Mr. Koff as a pioneer in the gas turbine industry whose leadership produced a host of innovative breakthroughs in design and development. He received the award at the SAE 2012 Power Systems Conference held October 30–November 1 in Phoenix, Arizona.

The American Institute of Aeronautics and Astronautics (AIAA) is pleased to announce that the **2013 AIAA Pendray Aerospace Literature Award** has been won by **Ronald F. Probst**, Ford Professor of Engineering, Emeritus, Massachusetts Institute of Technology. Dr. Probst received the award at a luncheon on January 8, as part of the 51st AIAA Aerospace Sciences Meeting at the Gaylord Texan Hotel and Convention Center, Grapevine, Texas. Dr. Probst is being honored for his “Seminal contributions to hypersonics, synthetic fuels, water purification, and physicochemical hydrodynamics.” The AIAA Pendray Aerospace Literature Award, named for Dr. G. Edward Pendray, a founder and past president of the American Rocket Society, honors outstanding contributions to aeronautical and astronautical literature.

Bruce E. Rittmann, Regents’ Professor of Environmental Engineering

and director, Swette Center for Environmental Biotechnology, Bidesign Institute, Arizona State University, is now a **Distinguished Member** of the American Society of Civil Engineers (ASCE), recognized “for exemplary advances to research and practice in environmental engineering, contributions to the technical literature, education of students, and professional leadership around the world.” An ASCE Distinguished Member honor is bestowed on those who have attained acknowledged eminence in a branch of engineering or in the arts and sciences, including the fields of engineering education and construction. Professor Rittmann is a leading expert in development of microbial systems to capture renewable resources and alleviate environmental pollution. His research combines microbiology, biochemistry, geochemistry, and microbial ecology for the purposes of restoring water purity and generating usable energy from waste products.

Esther Takeuchi, SUNY Distinguished Professor with a joint appointment in the Department of Chemistry and the Department of

Materials Science and Engineering Chemistry, Stony Brook University, and the chief scientist for the US Department of Energy’s Brookhaven National Laboratory’s Global and Regional Solutions Directorate, has been selected a **Fellow of the Electrochemical Society (ECS)**. The ECS, a professional organization concerned with various phenomena related to electrochemical and solid-state science and technology, boasts membership of more than 8,000 scientists and engineers worldwide, with no more than three percent honored with the distinction of fellow. Professor Takeuchi, an expert in the multidisciplinary field of energy storage technology, was honored at the 222nd Biannual ECS meeting held in October in Honolulu, Hawaii. She was cited for the development of the silver vanadium oxide battery and innovations in other medical battery technologies that improve the health of millions of people. The honor references Professor Takeuchi’s breakthrough invention of compact lithium batteries found in implantable cardiac defibrillators, which use electrical shocks to correct dangerous arrhyth-

mia and bring the heart back into normal rhythm.

Jeffrey Wadsworth, president and chief executive officer, Battelle, was honored at the TMS 2013 Annual Meeting and Exhibition in San Antonio, Texas, on March 5, 2013. Dr. Wadsworth will accept the prestigious **Acta Materialia Inc. Materials and Society Award** and act as a keynote speaker at a special TMS2013 symposium organized in his honor, titled Global R&D Trends—Implications for Material Sciences.

G. Paul Willhite, Ross H. Forney Distinguished Professor of Chemical and Petroleum Engineering, University of Kansas, was awarded **Society of Petroleum Engineers (SPE) Honorary Membership** at the 2012 SPE annual conference. The honor goes to those “who have given outstanding service to SPE and/or who have demonstrated distinguished scientific or engineering achievements in the fields within the technical scope of SPE.” Honorary membership is limited to only one-tenth of 1 percent of the 104,000 members of SPE.

2012 Japan-America Frontiers of Engineering Symposium Held at Beckman Center

On October 29–31, 2012, NAE hosted the Japan-America Frontiers of Engineering (JAFOE) Symposium at the Arnold and Mabel Beckman Center in Irvine, California. The Engineering Academy of Japan is NAE’s partner in this endeavor. NAE member **Katharine Frase**, vice president of industry solutions and emerging business at IBM, and Ichiro Kanaya, associate professor in

the Graduate School of Engineering Science at Osaka University, co-chaired the symposium.

Typical of the design of the bilateral FOEs, this meeting brought together approximately 60 engineers, ages 30–45, from US and Japanese universities, companies, and government labs for a 2½-day meeting, where leading-edge developments in four engineering fields

were discussed. The four sessions at the meeting were Video Content Analysis, Engineering for Natural Disaster Resiliency, Engineering for Agriculture: Providing Global Food Security, and Sports Engineering. Presentations given by two Japanese and two Americans in each of the four areas covered such topics as intelligent video surveillance, post-earthquake damage screening



Participants in the 2012 Japan-America Frontiers of Engineering Symposium held at the Beckman Center in Irvine, California.

of structures, applications of precision agriculture in rural communities, and biomechanical analysis of the motion of professional baseball pitchers.

The first evening's dinner speech was given by Dr. **Maxine Savitz**, NAE vice president and retired general manager of technology partnerships at Honeywell, Inc. She spoke about the workings of the President's Council of Advisors on Science and Technology and the role of informed private citizens in formulating science and technology policy in the United States. Other highlights included a poster session on the first afternoon that allowed all participants to describe their technical work or research and a tour of the Newport Beach Vineyards and Winery.

The next JAFEO symposium will be held in 2014 in Japan.

Funding for this activity was provided by The Grainger Foundation, the US National Science Foundation, and the Japan Science and Technology Agency.

NAE has been hosting an annual US Frontiers of Engineering meeting since 1995, and JAFEO meetings started in 2000. NAE has additional bilateral Frontiers of Engineering programs with Germany, 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.

The FOE meetings bring together outstanding engineers from industry, academe, and government at a relatively early point in their

careers since all the participants are 30–45 years old. Frontiers provides 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 meeting also facilitates the establishment of contacts and collaboration among the next generation of engineering leaders.

For more information about the symposium series, visit www.nae-frontiers.org. To nominate an outstanding engineer to participate in future Frontiers meetings, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or jhunziker@nae.edu.

NAE Energy Ethics Video Challenge Results

The NAE's Center for Engineering, Ethics, and Society held an Ethics Video Challenge in the fall of 2012 on the ethics of energy choices and energy research. Students across the country submitted 18 videos. The videos focused on topics from fracking to wind farms, from nuclear waste disposal to smart grids, from

use of public transportation to the energy costs of the meat industry. The students and their faculty advisors reported learning a lot about ethics through the project (Figure 1), and over 70% made use of NAE's very popular Online Ethics Center for Engineering and Research (www.onlineethics.org).

The Best Video Award went to Stephanie Annessi, Monique Blake, Xinyi Liu, and Rajiha Mehdi from Smith College for their video "Transnational Nuclear Waste Site Selection." Donna Riley, associate professor of engineering at Smith College, advised the team. The video examined issues of fairness and

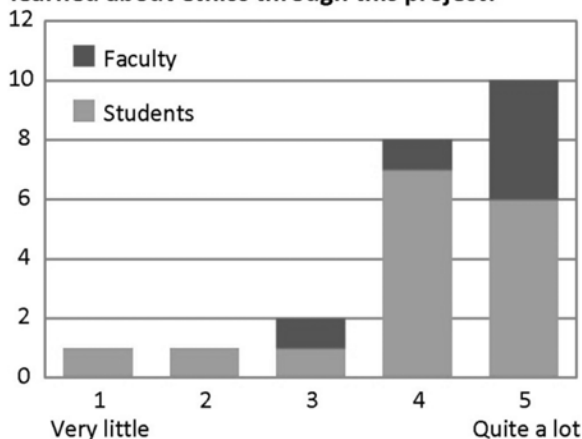
exploitation in the decision-making process for nuclear waste site selection, considering economic power imbalances and health impacts on an international level. The students argued that a good method for making these decisions was to use the model established by the European Repository Development Organization. This video also received the best video award in the theme area of "Directions for Energy Policy: Issues of Fairness and Sustainability." Other prizes were awarded for best in a topic area and "people's choice." All the winning videos are posted online at <http://onlineethics.org/Projects/VideoChallenge.aspx>.

A five-person judging panel selected the video challenge awards. Panelists were **John Ahearne**, NAE member and Executive Director Emeritus of Sigma Xi; Stephanie J.

Bird, coeditor of *Science and Engineering Ethics*; **Glen Daigger**, NAE member and Chief, Wastewater Process Engineering, CH2M Hill; Kristin Shrader-Frechette, the O'Neill Family Professor, Department of

Biological Sciences and Department of Philosophy at the University of Notre Dame; and Chris Schairbaum, Director of Energy Technology Strategy at Texas Instruments.

How much do you believe you (or your advisees) learned about ethics through this project?



NAE Annual Meeting, October 6–7, 2013

The 2013 NAE Annual Meeting will be held October 6–7 at the NAS Building of the National Academies in Washington, DC. Members of the NAE Class of 2013 will meet on Saturday, October 5, for an orientation. That evening the new members and foreign associates will attend a black tie dinner in their honor hosted by the NAE Council.

The induction ceremony for the Class of 2013 will be held at noon on Sunday, October 6, followed by the awards program.

On Monday morning, October 7, there will be the Business Session for members and foreign associates, followed by the Forum. In the afternoon, the section meetings will take place at the NAS Building and the Keck Center. The Annual Meeting concludes with an optional dinner dance at the JW Marriott.

The flyer for the NAE 2013 Annual Meeting will be mailed in June and will also be available on the NAE website. At that time you will be able to register online at www.nae.edu.

A Message from NAE Vice President Maxine L. Savitz



Maxine L. Savitz

In 2012, NAE raised \$5.3 million in private funds to support our efforts to strengthen the engineering profession and engage the public about the opportunities that come from engineering. This amounts to an impressive 28% increase over 2011 fundraising totals and a 34% increase over our 2010 fundraising totals. Of the total, \$2.5 million was raised to support unrestricted funds, the overwhelming majority of it from NAE members. Without these important funds, NAE would not have a solid foundation from which to sustain our most successful projects and spearhead the creation of new and timely programs. The energetic participation of our members has always driven NAE

forward with crucial time, effort, and ideas. Our members are also vital to our fundraising success, both by making financial contributions of their own and by serving as advocates for NAE and engineering to their peers. We sincerely appreciate your generosity and continual support.

Madni Challenges

Last year, NAE held two matching gift challenges, both sponsored by Dr. Asad M. Madni ('11) and his family. *The Asad, Taj, and Jamal Madni Challenge for Newer Members*, which matched any gift from a member of the classes of 2009, 2010, 2011, or 2012, exceeded its \$50,000 goal to raise \$148,568. *The Asad, Taj, and Jamal Madni Section 7 Challenge*, which matched any increase in a Section 7 member's 2012 giving over that of the preceding year, was even more successful, raising \$203,000. It also helped enable a 3% jump in giving participation in Section 7, to 25%, from the previous year. Dr. Madni sponsored these challenges to inspire his fellow NAE members to support NAE's mission and to help NAE reach its most

ambitious 50th Anniversary goal: 50% participation by NAE members in the fundraising effort.

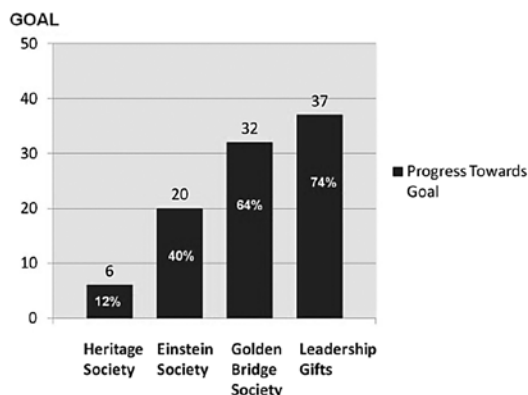
50th Anniversary

NAE will celebrate its 50th Anniversary in 2014. In 2011, NAE embarked on a four-year fundraising effort to Celebrate 50 Years of Engineering Leadership and Service to the nation. Through your gifts, NAE can strengthen its voice on national policy; work to increase the number, quality, and diversity of US engineering graduates; and advance our national capacity for 21st century innovation and global competitiveness. Now, halfway through the campaign, we have made impressive progress toward our "50 for 50" goals.

While we are well on our way to meeting many of our goals, we are behind in achieving our goal to reach 50 new Heritage Society members/ 50 new planned gifts by the anniversary. If you are interested in making a planned gift to NAE, or if you have made a gift provision in your estate plans but not yet notified us, please contact Radka Nebesky at 202-334-3417 or RNebesky@nae.edu.

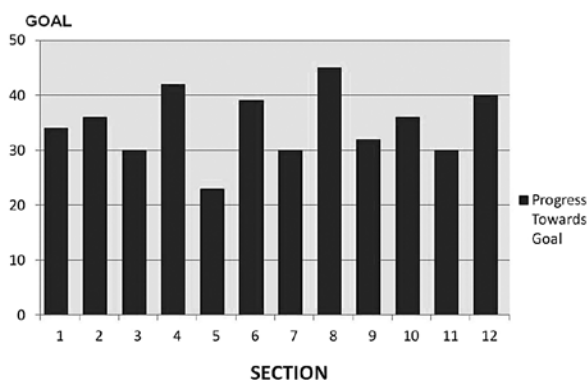
Increase in Society Membership and Leadership Gifts

Counting from January 1, 2011



Percent Participation by Section

Counting Period: Jan. 1, 2011 to Dec. 31, 2014



By finishing a strong, successful fundraising effort in 2014, NAE can position itself to continue its leadership role in promoting engineering and serving the nation by advising intelligent engineering solutions to 21st century challenges.

Vest President's Opportunity Fund

In June of 2013, Dr. Charles M. Vest will finish his term as NAE President. During his tenure, Dr. Vest has championed the creation of Frontiers of Engineering Education (FOEE), taken the lead in developing a new Manufacturing, Design, and Innovation (MDI) Initiative, and continued to harness the Grand Challenges as a tool to capture young people's imagination. To honor Chuck and to strengthen NAE for the future, we have established the Charles M. Vest President's Opportunity Fund with a goal to raise \$10 million by May of this year. To date we have \$2.3 million in gifts, pledges, and gift intentions. This new fund will support exploratory studies, seed new initiatives, and supplement strategic programs, as directed by the president of NAE. The discretionary money will empower NAE to be proactive in identifying and leading initiatives to benefit the nation and profession. Any gift made to the Vest President's Opportunity Fund will also count toward the 50th Anniversary. Thank you to the donors who have already contributed so generously in honor of Chuck. Please see page 66 for a list of donors to the fund.

Significant Contributions

I also want to highlight some remarkable gifts NAE received in 2012. While all contributions are greatly appreciated and make a difference

in the work of NAE, the following gifts show extraordinary leadership and commitment to NAE. Names in bold are NAE members.

- **Erich Bloch ('80)** for his \$100,000 gift to the NAE Independent Fund.
- **Stephen D. Bechtel, Jr. ('75)** and the S.D. Bechtel, Jr. Foundation for contributing \$150,000 to the Charles M. Vest President's Opportunity Fund and Public Understanding of Engineering.
- Deere & Company for giving \$150,000 to support the upcoming National Engineering Forum.
- The Charles Stark Draper Laboratory for contributing \$400,000 to cover operating costs of the Draper Prize for the advancement of engineering and public education about engineering.
- **Joseph Goodman ('87)** for making a \$500,000 bequest provision to NAE in his will.
- **Chad ('76)** and Ann Holliday for contributing \$100,000 to the Charles M. Vest President's Opportunity Fund.
- **Irwin ('76)** and Joan Jacobs for committing \$1,000,000 to the Charles M. Vest President's Opportunity Fund.
- W.M. Keck Foundation for its \$500,000 gift to endow and name the Founders Award in honor of **Si Ramo ('64)**, the last living founding member of NAE. The *Si Ramo Founders Award* will continue to recognize NAE members and foreign associates who demonstrate the ideals and principles of NAE in their work.
- John F. McDonnell and the JSM Charitable Trust for investing

\$1,000,000 in Frontiers of Engineering Education (FOEE), a program to encourage and promote effective and innovative engineering instruction.

- Ohio University Foundation for contributing \$166,676 to cover operating costs associated with awarding the Russ Prize, recognizing engineering achievements that have a significant and widespread impact on society.

Loyal Donors

Gifts made regularly each year to NAE also demonstrate genuine commitment to our mission and goals. As a long-time donor who understands that every donation to NAE is a choice to support an organization whose work I believe matters greatly, I thank the following people who have contributed to NAE for 15 consecutive years or more:

Clarence R. Allen ('76)
Charles A. Amann ('89)
John C. Angus ('95)
Wm. Howard Arnold ('74)
Harold Brown ('67)
Jack E. Buffington ('96)
Esther M. Conwell ('80)
Irwin Dorros ('90)
Daniel J. Fink ('74)
Robert C. Forney ('89)
Anita K. Jones ('94)
Johanna M. Levelt Sengers ('92)
Thomas S. Maddock ('93)
Jack S. Parker ('76)
Simon Ramo ('64)
William R. Schowalter ('82)
F. Stan Settles ('91)
Morris Tanenbaum ('72)
Hardy W. Trolander ('92)
Andrew J. Viterbi ('78)
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Randal E. Bryant	Manuel Elices	William J. Hall	Bill and Ann Koros
Jack E. Buffington	Menachem Elimelech	Thomas L. Hampton	Richard W. Korsmeyer [◊]
James D. Callen	Bruce R. Ellingwood	Niels Hansen	Gerald L. Kulcinski
Joe C. Campbell [§]	Tony F. Embleton	William H. Hansmire	John M. Kulicki
John M. Campbell	Richard E. Emmert	John M. Hanson	Derrick M. Kuzak [◊]
Max W. Carbon [◊]	Joel S. Engel [§]	James S. Harris [◊]	Stephanie L. Kwolek
E. Dean Carlson	John V. Evans [§]	Henry J. Hatch	Richard T. Lahey
William J. Carroll	Lawrence B. Evans	Adam Heller	T.W. Lambe
William Cavanaugh	Robert M. Fano	Martin E. Hellman [§]	James L. Lammie

*Deceased

[§]Madni Section 7 Challenge

[◊]Madni Challenge for Newer Members

David A. Landgrebe	James A. Miller	Robert H. Rediker [§]	Gerald B. Stringfellow
William W. Lang	Warren F. Miller	Eli Reshotko	Stanley C. Suboleski
Carl G. Langner	Keith K. Millheim	John R. Rice	James M. Symons
Robert C. Lanphier	Richard K. Moore*	Jerome G. Rivard	Rodney J. Tabaczynski
Louis J. Lanzerotti	John W. Morris	Stephen M. Robinson	James M. Tien
Cato T. Laurencin [◊]	Walter E. Morrow [§]	Stanley T. Rolfe	William F. Tinney
Alan Lawley	A. Stephen Morse [§]	Arye Rosen [§]	Spencer R. Titley
Margaret A. LeMone	Gerard A. Mourou [§]	Howard B. Rosen	Alvin W. Trivelpiece
Johanna M. Levelt	Earll M. Murman	Kenneth M. Rosen	Stephen D. Umans [◊]
Sengers	Gerald Nadler	Arthur H. Rosenfeld [◊]	John M. Undrill [◊]
Herbert S. Levinson	Devaraysamudram R.	Hans T. Rossby	Moshe Y. Vardi
Kenneth Levy	Nagaraj	Jean E. Sammet	Walter G. Vincenti
Salomon Levy	R. Shankar Nair	Peter W. Sauer	Thomas H. Vonder Haar
Paul A. Libby	Alan Needleman	Thorndike Saville	Irv Waaland
Peter W. Likins	Stuart O. Nelson	Robert F. Sawyer	Wallace R. Wade [◊]
Robert A. Lindeman [◊]	Joseph H. Newman	Robert S. Schechter	Steven J. Wallach
Kuo-Nan Liou	Robert E. Nickell	Robert A. Scholtz [◊]	C. Michael Walton
Nathan and Barbara	David Okrent*	Walter J. Schrenk	John D. Warner
Liskov	Robert S. O'Neil	Albert B. Schultz	Michael S. Waterman
Andrew J. Lovinger	Elaine S. Oran	Mischa Schwartz [§]	John T. Watson
Mark and Mary	David H. Pai	Norman R. Scott	Wilford F. Weeks
Lundstrom [◊]	Athanasios Z.	Hratch G. Semerjian	Robert J. Weimer
Verne L. Lynn	Panagiotopoulos	Robert J. Serafin	Lawrence M. Wein [◊]
J. Ross and Margaret	Stavros S. Papadopoulos [◊]	F. Stan Settles	Sheldon Weinbaum
Macdonald [§]	Bradford W. and Virginia	Don W. Shaw	Andrew M. Weiner [§]
Malcolm MacKinnon	W. Parkinson	Thomas B. Sheridan	Sheldon Weinig
Subhash Mahajan	Donald R. Paul	Martin B. Sherwin	Paul B. Weisz
James W. Mar	Arogyaswami J. Paulraj [§]	Neil G. Siegel	Jasper A. Welch
William F. Marcuson	H.W. Paxton	Daniel P. Siewiorek	Marvin H. White [§]
Robert C. Marini	Donald W. Peaceman	Arnold H. Silver [§]	Robert M. White
Hans Mark	P. Hunter Peckham	Peter G. Simpkins	Robert V. Whitman*
James J. Markowsky	Norbert J. Pelc [◊]	R. Paul Singh	David A. Woolhiser
Tobin J. Marks	Alan W. Pense	Jack M. Sipress [§]	Eli Yablonovitch [§]
David K. Matlock	Nicholas A. Peppas	Alvy R. Smith	Roe-Hoan Yoon
William C. Maurer	John H. Perepezko	Henry I. Smith [§]	Laurence R. Young
Walter J. McCarthy	Henry Petroski	Gurindar S. Sohi [◊]	Paul Zia
William J. McCroskey	Karl S. Pister	Soroosh Sorooshian	Ben T. Zinn
William McGuire	Stephen B. Pope [◊]	Alfred Z. Spector	Dusan S. Zrnic
Ross E. McKinney	Michael Prats	Dale F. Stein	
Diane M. McKnight [◊]	William R. Prindle	Dean E. Stephan	<i>Friends</i>
Robert M. McMeeking	Ronald F. Probstien	Gregory Stephanopoulos	Sharon P. Gross
Terence P. McNulty	Charles W. Pryor	Thomas G. Stephens	Radka Z. Nebesky
Alan L. McWhorter [§]	Edwin P. Przybylowicz	Kenneth H. Stokoe	Elizabeth J. Szekely
Chiang C. Mei	Kaushik Rajashekara [◊]	Howard and Valerie	Elizabeth Whitman
Harry W. Mergler [§]	Vivian and Subbiah	Stone [◊]	
Angelo Miele	Ramalingam	Richard G. Strauch	

*Deceased

§Madni Section 7 Challenge

◊Madni Challenge for Newer Members

Tributes

In memory of James R. Burnett – Anne Burnett

In memory of Michiko So – Lawrence S. Finegold

In memory of Daniel J. Fink – Tobie Fink

In memory of William Gross – Sharon Gross

In memory of Howard S. Jones – Evelyn S. Jones

FOUNDATIONS, CORPORATIONS, AND OTHER ORGANIZATIONS

Lifetime

In recognition of foundations, corporations, and other organizations that have made lifetime contributions of \$1 million or more to NAE.

AT&T Corporation	E.I. du Pont de Nemours	JSM Charitable Trust	O'Donnell Foundation
S.D. Bechtel Jr.	& Company	Lockheed Martin	The Ohio University
Foundation	Ford Motor Company	Corporation	Foundation
The Boeing Company	General Electric Company	McDonnell Douglas	Robert Pritzker Family
DaimlerChrysler	General Motors Company	Corporation	Foundation
Corporation	The Grainger Foundation	The Andrew W. Mellon	Alfred P. Sloan
The Charles Stark Draper	International Business	Foundation	Foundation
Laboratory	Machines Corporation		

Annual

In recognition of foundations, corporations, and other organizations that contributed to NAE in 2012.

A-dec, Inc.	Cummins Business	GE Foundation	Margaret and Ross
Avid Solutions Industrial	Services	Arthur and Linda Gelb	Macdonald Charitable
Process Control	The Thomas and Bettie	Charitable Foundation	Fund of Triangle
The Bechtel Foundation	Deen Charitable Gift	Genentech, Inc.	Community Foundation
S.D. Bechtel Jr.	Fund	General Electric Company	Microsoft Corporation
Foundation	Deere & Company	Geosynthetic Institute	Microsoft Matching
Bell Family Foundation	The Walt Disney	Gerstner Family	Gift Program/Giving
Tom and Becky Bergman	Company	Foundation	Campaign
Fund	The Dow Chemical	Gratis Foundation	Mobil Foundation, Inc.
Elwyn and Jennifer	Company	Hines Interests Limited	Gordon and Betty Moore
Berlekamp Fund	The Charles Stark Draper	Partnership	Foundation
Bessemer Trust	Laboratory	IEEE	Dale and Marge Myers
The Bodman Foundation	Employees Charity	International Business	Fund at the San Diego
The Boeing Company	Organization of	Machines Corporation	Foundation
Branscomb Family	Northrop Grumman	Joan and Irwin Jacobs	Occidental Petroleum
Foundation	EOvation Advisors, LLC	Fund of the Jewish	Corporation
CA Technologies	ExxonMobil Foundation	Community Foundation	The Ohio University
Castaing Family	Farrell Family Foundation	JSM Charitable Trust	Foundation
Foundation	Michiko So Finegold	W.M. Keck Foundation	Donald and Jo Anne
Chevron Humankind	Memorial Trust	Gloria and Ken Levy	Petersen Fund
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Qualcomm, Inc.	Southwest Research	TBL Foundation	University of Rochester
Henry M. Rowan Family	Institute	The Jim and Elizabeth	Verizon Communications
Foundation	Ray and Maria Stata	Turner Fund of the	Verizon Foundation
Samueli Foundation	Family Charitable Trust	AYCO Charitable	Viterbi Family Grant
Tawny and Jerry Sanders	of November 1983	Foundation	Fund of the Jewish
Charitable Foundation	Strategic Decisions, LLC	United Engineering	Community Foundation
Henry G Schwartz Jr &	Strategic Worldwide, LLC	Foundation	The Woolard Family
Sally D Schwartz 2010	Morris and Charlotte	United Way of Greater	Foundation
Family Foundation	Tanenbaum Family	Los Angeles	Zarem Foundation
	Foundation		

We have made every effort to list donors accurately and according to their wishes. If we have made an error, please accept our apologies and contact the Development Office at 202.334.2431 so we can correct our records.

Calendar of Meetings and Events

March 1–31	Election of NAE Officers and Councillors	April 10	Bridging the Gender Gap in Innovation—Role Models for the Future: A Swiss and US Perspective Newseum, Washington, DC	May 9–10	NAE Council Meeting
March 5	Regional Meeting Stanford University, California			May 15–17	China-America Frontiers of Engineering Beijing, China
March 13	Coalition on Women in STEM Meeting	April 22	NAE Convocation of the Professional Engineering Societies	May 20	NAE Regional Meeting University of Arizona, Tucson
March 28	Regional Meeting Georgia Institute of Technology, Atlanta	April 23–24	Committee on Career Outcomes of Engineering Bachelor's Degree Recipients Meeting	June 6–7	Committee on Women in Science, Engineering, and Medicine Meeting Irvine, California
April 1	Deadline for nominations for 2013–2014 NAE awards	April 24–26	Sustainable Cities and Interdisciplinary International Education Workshop: Core Knowledge and Skills	All meetings are held in National Academies facilities in Washington, DC, unless otherwise noted.	
April 3–4	NAE-NRC Planning Meeting on Undergraduate Education				
April 4	NAE Regional Meeting Carnegie Mellon University, Pittsburgh, Pennsylvania	April 26–28	German-American Frontiers of Engineering Irvine, California		
April 8–13	National Institute for Energy Ethics and Society Arizona State University	April 29	NAE Regional Meeting University of Minnesota, Minneapolis		

In Memoriam

JOHN E. ANDERSON, 83, retired senior corporate fellow, Praxair, Inc., died on November 4, 2012. Dr. Anderson was elected to NAE in 1991 “for combining novel engineering concepts with combustion science to reduce atmospheric pollution and improve fuel efficiency in industrial combustion processes.”

RICHARD E. BALZHISER, 80, president emeritus, Electric Power Research Institute, Inc., died on December 23, 2012. Dr. Balzhiser was elected to NAE in 1994 “for leadership in the management of energy research and technological development.”

SIDNEY A. BOWHILL, 85, emeritus professor of electrical engineering, University of Illinois, died on October 4, 2012. Dr. Bowhill was elected to NAE in 1971 “for contributions to aeronomy and the fostering of national and international programs in radio research.”

JOHN C. CALHOUN JR., 95, Distinguished Professor emeritus, Texas A&M University, died on November 29, 2012. Dr. Calhoun was elected to NAE in 1985 “for outstanding contributions to the art and science of petroleum recovery, to the development of engineering education, and to the use and understanding of engineering in the public arena.”

MAURICE C. FUERSTENAU, 79, professor emeritus of metallurgy, College of Engineering, University of Nevada, died on October 7, 2012. Dr. Fuerstenau was elected to NAE in 1991 “for contributions to mineral processing, hydrometallurgy, and engineering education.”

HENRY J. GRUY, 97, chairman, H.J. Gruy and Associates, Inc., died on December 19, 2012. Mr. Gruy was elected to NAE in 1989 “for contributions in oil and gas evaluations and for leadership in the petroleum industry.”

WILLIAM J. HARRIS JR., 94, retired consultant, died on December 5, 2012. Dr. Harris was elected to NAE in 1977 “for research and development, technical planning, and systems analysis for the railroad industry, and contributions to the materials field.”

CHARLES H. HOLLEY, 93, retired manager, Turbine Technology, General Electric Company, died on October 9, 2012. Mr. Holley was elected to NAE in 1976 “for pioneering contributions to the evolution of turbine-generator design.”

D. BRAINERD HOLMES, 91, retired president, Raytheon Company, died on January 11, 2013. Mr. Holmes was elected to NAE in 1977 “for contributions to large electronic systems and leadership in manned space flight and industrial management.”

ALLEN F. JACOBSON, 86, retired chairman and CEO, 3M, died on November 1, 2012. Mr. Jacobson was elected to NAE in 1991 “for leadership in manufacturing efficiency, product quality, and innovative technology.”

JAMES R. KATZER, 71, retired manager, Strategic Planning and Performance Analysis, ExxonMobil Research; affiliate professor, CBE, Iowa State University; and independent consultant, died on November 2, 2012. Dr. Katzer was elected to NAE in 1998 “for research on catalysis and reaction engineering, and leadership in commercializing catalytic processes.”

JAMES F. LARDNER, 88, retired vice president, Tractor and Component Operations, Deere & Company, died on December 17, 2012. Mr. Lardner was elected to NAE in 1985 “for a major influence on the advancement of manufacturing technology through both engineering concepts and engineering applications.”

TINGYE LI, 81, retired division manager, Communications Infrastructure Research Laboratory, AT&T Laboratories Research, died on December 27, 2012. Dr. Li was elected to NAE in 1980 “for co-discovering the existence of low-loss electromagnetic-wave modes in open structures with application to laser resonators.”

WILLIAM McGUIRE, 92, professor emeritus of civil and environmental engineering, Cornell University, died on January 31, 2013. Mr. McGuire was elected to NAE in 1994 “for contributions to the understanding of the behavior of steel structures and the development of computer graphics capabilities for design of those structures.”

RICHARD K. MOORE, 89, Black and Veatch Professor emeritus and director emeritus, Radar Systems and Remote Sensing Lab, University of Kansas, died on November 13, 2012. Dr. Moore was elected to NAE in 1989 “for pioneering achievements in radar remote sensing of the land and oceans from air and space platforms.”

RICHARD M. MORROW, 86, retired chairman, Amoco Corporation, died on January 21, 2013. Mr. Morrow was elected to NAE in 1986 “for outstanding engineering and management contributions to oil and gas production in harsh environments, and for contributions to worldwide chemicals production.”

RICHARD B. NEAL, 95, retired associate director, Stanford Linear Accelerator Center, Stanford University, died on November 22, 2012. Dr. Neal was elected to NAE in 1979 “for leadership in the design and construction of multi-GeV linear electron accelerators.”

DAVID OKRENT, 90, professor emeritus of engineering and applied science, University of California, Los Angeles, died on

December 14, 2012. Dr. Okrent was elected to NAE in 1974 “for contributions in fast reactor design, including critical experiments, safety tests and analyses, and neutron cross-section evaluation.”

JAMES W. PLUMMER, 93, retired chairman, Board of Trustees, The Aerospace Corporation, died on January 16, 2013. Mr. Plummer was elected to NAE in 1978 “for contributions to the design, development, and operation of unmanned military satellites.”

IRVING S. REED, 88, professor emeritus of electrical engineering, University of Southern California, died on September 11, 2012. Dr. Reed was elected to NAE in 1979 “for contributions to automatic detection and processing of radar data, multiple-error-correcting communications codes, and digital computer design.”

GEORGE A. ROBERTS, 93, retired chairman, Teledyne, Inc., died on February 15, 2013. Dr. Roberts was elected to NAE in 1978 for his “technological advances, managerial leadership, and continuing role in professional activities.”

SHOICHI SABA, 93, executive advisor, Toshiba Corporation, died on September 10, 2012. Mr. Saba was elected a foreign associate of NAE in 1991 “for the development and application of electrical transmission systems and devices, and industrial manufacturing leadership.”

ALFRED SAFFER, 93, retired vice chairman, Halcon SD Group, Inc.,

died on September 7, 2012. Dr. Saffer was elected to NAE in 1978 “for inventing, developing, engineering, and commercializing several chemical processes, and leadership in the chemical industry.”

MICHAEL R. SFAT, 90, retired president, Bio-Technical Resources, died on October 16, 2012. Mr. Sfat was elected to NAE in 1994 “for initial studies on aeration in fermenters, novel developments in food biotechnology, and sustained industrial entrepreneurship.”

LAWRENCE H. SKROMME, 99, retired, consulting agricultural engineer, died on December 3, 2012. Mr. Skromme was elected to NAE in 1978 “for expansion and application of agricultural engineering technology coordinated with human resources in reproductive service to humankind.”

WILLIAM E. SPLINTER, 86, director, Larsen Tractor and Power Museum, died on September 26, 2012. Dr. Splinter was elected to NAE in 1984 “for invention and development of safer aerial spray systems and improved harvesting systems which have promoted a better environment and stronger agriculture.”

BERNARD A. VALLERGA, 91, independent consultant, died on January 5, 2013. Mr. Vallerga was elected to NAE in 1987 “for unique achievements and novel applications in asphalt technology; pavement design, rehabilitation, and recycling; hydraulic revetments; membranes; and soil stabilization.”

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 (800) 624-6242. (*Note: Prices quoted are subject to change without notice. There is a 10 percent discount for online orders when you sign up for a MyNAP account. Add \$6.50 for shipping and handling for the first book and \$1.50 for each additional book. Add applicable sales tax or GST if you live in CA, CT, DC, FL, MD, NY, NC, VA, WI, or Canada.*)

Educating Engineers: Preparing 21st Century Leaders in the Context of New Modes of Learning: Summary of a Forum. Engineering education is changing in the United States and around the world in response to integration with new science, particularly nanoscale science and biology; increased emphasis on innovation and entrepreneurship to drive economic growth; accelerating speed, complexity, and globalization of engineering functions; preparation of graduates to address the Grand Challenges; efforts to empower a more diverse population of young American engineers; renewed commitment to design and production; and new approaches to large-scale engineering systems that must engage society. As in all of higher education, there are also significant

challenges such as declining financial support and vast opportunities such as interactive online learning and massive open online courses. What lies ahead? What are the ramifications for engineering schools? During the 2012 NAE Annual Meeting Forum an expert panel explored many facets of these challenges and opportunities and offered guidance on the roles and responsibilities of 21st century engineering educators. This report is a summary of that discussion.

NAE members on the panel were **Linda P.B. Katehi**, chancellor, University of California, Davis, and **Richard K. Miller**, president and professor of mechanical engineering, Franklin W. Olin College of Engineering. Paper, \$32.00.

Pathways to Urban Sustainability: A Focus on the Houston Metropolitan Region: Summary of a Workshop. A workshop was convened to explore the region's approach to urban sustainability, with an emphasis on building the evidence base for new policies and programs. Participants examined how the interaction of various systems (natural and human; energy, water, and transportation) affected the region's social, economic, and environmental conditions. The objectives were to discuss ways that regional actors are approaching sustainability, specifically, how they are attempting to merge environmental, social, and economic objectives; share information about activities and strategic planning efforts, including lessons learned; examine the role of

science, technology, and research in supporting efforts to make the region more sustainable; and explore how federal agency efforts, particularly interagency partnerships, can complement or leverage the efforts of other key stakeholders. The workshop was designed to explore the complex challenges facing sustainability efforts in the Houston metropolitan region and innovative approaches to address them, as well as performance measures to gauge success and opportunities to link knowledge with action. In developing the agenda, the planning committee chose topics that were timely and cut across the concerns of individual institutions, reflecting the interests of a variety of stakeholders.

NAE member **Glen T. Daigger**, senior vice president and chief technology officer, CH2M Hill, served on the workshop steering committee. Paper, \$38.00.

Public Response to Alerts and Warnings Using Social Media: Report of a Workshop on Current Knowledge and Research Gaps. Following an earlier NRC workshop on public response to alerts and warnings delivered to mobile devices, a workshop in February 2012 looked at the role of social media in disaster response. One of the first workshops to specifically address the use of social media for alerts and warnings, the event brought together social science researchers, technologists, emergency management professionals, and other experts on public and emergency managers' use of

social media in disasters. Presenters and participants considered what is known about how the public responds to alerts and warnings, the implications of what is known about such responses for the use of social media to provide alerts and warnings to the public, and approaches to enhancing the situational awareness of emergency management as well as privacy considerations. This report summarizes the presentations and discussions, points to potential topics for future research (and possible areas for future research investment), and describes some of the challenges facing disaster managers who wish to incorporate social media into regular practice.

NAE member **Jon M. Kleinberg**, Tisch University Professor, Cornell University, was a member of the study committee. Paper, \$38.00.

Terrorism and the Electric Power Delivery System. The electric power delivery system that carries electricity from large central generators to customers could be severely damaged by a small number of well-informed attackers with little risk of detection, and well-planned and coordinated attacks by terrorists could partially disable the system in a large region of the country for a very long time. Electric systems are not designed to withstand or quickly recover from damage inflicted simultaneously on multiple components. The system's inherent vulnerability (transmission lines may span hundreds of miles, many facilities are unguarded) is exacerbated by the fact that the power grid, most of which was originally designed to meet the needs of individual vertically integrated utilities, is being used to move power between regions to support the needs of competitive

markets for power generation. Furthermore, investment to strengthen and upgrade the grid has lagged, with the result that many parts of the system are heavily stressed. Because all parts of the economy, as well as human health and welfare, depend on electricity, the results of widespread and/or sustained power failure could be devastating. This report describes measures that could make the power delivery system less vulnerable to attacks, restore power faster after an attack, and make critical services less vulnerable during disruption of the delivery of conventional electric power.

NAE members on the study committee were **Anjan Bose**, Regents Professor and Distinguished Professor of Electric Power Engineering, Washington State University; **B. Don Russell Jr.**, Distinguished Professor and Regents Professor, Harry E. Bovay Jr. Endowed Chair, Department of Electrical Engineering, Texas A&M University, College Station; **Carson W. Taylor**, principal engineer, retired, Bonneville Power Administration; and **Vijay Vittal**, Ira A. Fulton Chair Professor, Department of Electrical Engineering, Ira A. Fulton School of Engineering, Arizona State University. Paper, \$49.00.

Disaster Resilience: A National Imperative. No person or place is immune to disasters or disaster-related losses. Natural hazards, infectious disease outbreaks, acts of terrorism, social unrest, and financial disasters all can have large-scale consequences for the nation and its communities. Beyond the unquantifiable costs of injury and loss of life, statistics for 2011 alone indicate that economic damages from natural disasters in the United States exceeded \$55 bil-

lion. One way to reduce the impacts of disasters is to invest in enhancing resilience—the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. This report defines “national resilience,” describes the state of knowledge about resilience to hazards and disasters, and frames the main issues related to increasing resilience in the United States. It provides goals, baseline conditions, or performance metrics for national resilience and outlines additional information, data, gaps, and/or obstacles to be addressed to increase the nation's resilience to disasters. And it presents recommendations for necessary approaches to elevate national resilience to disasters in the United States. Actions that move the nation from a reactive approach to a proactive stance, with communities actively engaged in enhancing resilience, will reduce many of the societal and economic burdens of disasters.

NAE members on the study committee were **Joseph A. Ahearn**, retired senior vice president, CH2M Hill, and Major General, US Air Force Civil Engineer; **Bernard Amadei**, professor of civil engineering, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder; and **Gerald E. Galloway Jr.**, Glenn L. Martin Institute Professor of Engineering, University of Maryland, College Park. Paper, \$49.00.

Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Tide gages show that global sea level rose about 7 inches during the 20th century, and recent satellite data show that the rate of sea-level rise is accelerating.

As Earth warms, sea levels are rising mainly because ocean water expands as it warms and water from melting glaciers and ice sheets is flowing into the ocean. Sea-level rise poses enormous risks to the infrastructure, development, and wetlands that line much of the 1,600 mile shoreline of California, Oregon, and Washington. These states asked the National Research Council to make independent projections of sea-level rise along their coasts for the years 2030, 2050, and 2100. This report describes the factors that affect sea level along the US west coast: climate patterns such as El Niño, effects from the melting of modern and ancient ice sheets, and geologic processes, such as plate tectonics.

NAE member **Robert A. Dalrymple**, Willard and Lillian Hackerman Professor of Civil Engineering, Whiting School of Engineering, Johns Hopkins University, was a member of the study committee. Paper, \$54.00.

NASA's Strategic Direction and the Need for a National Consensus. The National Aeronautics and Space Administration (NASA) is widely admired for astonishing accomplishments since its formation in 1958. Looking ahead, what will be NASA's goals and objectives, and what will be the strategy for achieving them? More fundamentally, how will the goals, objectives, and strategy be established and by whom? How will they be modified to reflect changes in science, technology, national priorities, and available resources? Following a request from Congress, NASA asked the National Research Council (NRC) to conduct a "comprehensive independent assessment of NASA's strategic direction and agency management." The NRC

Committee on NASA's Strategic Direction determined that only with a national consensus on the agency's future strategic direction can NASA continue to deliver the wonder, the knowledge, the national security and economic benefits, and the technology typified by its earlier history. This report summarizes the findings and recommendations of the committee.

NAE members on the study committee were **Albert Carnesale** (chair), chancellor emeritus and professor, University of California, Los Angeles; **Robert L. Crippen**, USN, ret., and president (retired), Thiokol Propulsion; and **Warren M. Washington**, senior scientist, Climate Change Research Section, Climate and Global Dynamics Division, National Center for Atmospheric Research. Paper, \$35.00.

Progress Toward Restoring the Everglades: The Fourth Biennial Review, 2012. Twelve years into the Comprehensive Everglades Restoration Project, little progress has been made in restoring the core of the remaining Everglades ecosystem; instead, most project construction has occurred along its periphery. To reverse ongoing ecosystem declines, it will be necessary to expedite restoration projects that target the central Everglades and to improve both the quality and quantity of the water in the ecosystem. The new Central Everglades Planning Project offers an innovative approach to this challenge, although additional analyses are needed at the interface of water quality and quantity to maximize restoration benefits within existing legal constraints.

NAE member **Charles T. Driscoll Jr.**, University Professor, Department of Civil and Environmental

Engineering, Syracuse University, was a member of the study committee. Paper, \$54.00.

A National Strategy for Advancing Climate Modeling. As climate change has pushed climate patterns beyond historic norms, the need for detailed projections is growing across all sectors, including agriculture, insurance, and emergency preparedness planning. This report emphasizes the need for climate models to evolve substantially in order to deliver climate projections at the scale and level of detail needed by decision makers. The report recommends an annual US climate modeling forum for the nation's diverse modeling communities and users of climate data, to enable users to learn more about the strengths and limitations of models and provide input to modelers on their needs, to foster discussion of priorities for national modeling, and to convene disparate climate science communities to design common modeling experiments. Progress will likely depend on a combination of enhanced model resolution, advances in observations, improved model physics, and more complete representations of the Earth system. The report suggests the continued use and upgrading of climate-dedicated computing resources at modeling centers, together with research on how to exploit the more complex computer hardware systems expected over the next 10 to 20 years.

NAE members on the study committee were **Robert E. Dickinson**, professor, Department of Geological Sciences, The University of Texas, Austin, and **Larry L. Smarr**, director, Calit2, University of California, San Diego. Paper, \$62.00.

Assuring the US Department of Defense a Strong Science, Technology, Engineering, and Mathematics (STEM) Workforce.

The ability of the US military to prevail during future conflicts, and to fulfill its humanitarian and other missions, depends on continued advances in the nation's technology base. A workforce with robust science, technology, engineering, and mathematics (STEM) capabilities is critical for sustaining US preeminence. But current STEM activities of the Department of Defense (DOD) are a small and diminishing part of the nation's overall science and engineering enterprise. This report presents five principal recommendations for attracting, retaining, and managing highly qualified STEM talent in the department based on an examination of the current STEM workforce of DOD and the defense industrial base. As outlined in the report, DOD should focus its investments to ensure that STEM competencies in all potentially critical, emerging areas are maintained at least at a basic level in the department and in its industrial and university bases.

NAE members on the study committee were **Norman R. Augustine** (co-chair), retired chairman and CEO, Lockheed Martin Corporation; **C.D. (Dan) Mote Jr.** (co-chair), Regents Professor and Glenn L. Martin Institute Professor of Engineering, University of Maryland; **Mary L. Good**, dean emeritus, special advisor to the chancellor for economic development, University of Arkansas at Little Rock, and former under secretary for technology, US Department of Commerce; **Robert J. Hermann**, private consultant, Bloomfield, Connecticut; **Anita K. Jones**, University Professor Emerita,

University of Virginia; **Frances S. Ligler**, US Navy senior scientist, Center for Bio/Molecular Science & Engineering, Naval Research Laboratory; **Paul D. Nielsen**, director and CEO, Software Engineering Institute, and Major General, USAF (retired); **C. Kumar N. Patel**, president and CEO, Pranalytica Inc.; and **Stephen M. Robinson**, professor emeritus, University of Wisconsin-Madison. Paper, \$44.00.

Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives.

An NRC committee assessed the feasibility, practicality, and affordability of US boost-phase missile defense compared with US non-boost missile defense when countering short-, medium-, and intermediate-range ballistic missile threats to deployed forces of the United States and its allies. The committee considered the following to be the missions for ballistic missile defense (BMD): protection of the US homeland against nuclear and other weapons of mass destruction (WMD) or conventional ballistic missile attacks; and protection of US forces, including military bases, logistics, command and control facilities, and deployed forces, including military bases, logistics, and command and control facilities. The committee also considered protection of US allies, partners, and host nations against ballistic-missile-delivered WMD and conventional weapons. This report, presenting the committee's findings and recommendations, sets guidelines for the future of BMD research and suggests that the United States take great care to ensure that negotiations on space agreements not

adversely affect missile defense effectiveness.

NAE members on the study committee were **L. David Montague** (co-chair), retired president, Missile Systems Division, Lockheed Martin Missiles & Space; **David K. Barton**, independent consultant, Hanover, New Hampshire; and **C. Kumar N. Patel**, president and CEO, Pranalytica, Inc. Paper, \$62.00.

Weather Services for the Nation: Becoming Second to None.

After the National Weather Service (NWS) completed a major Modernization and Associated Restructuring (MAR) in 2000, Congress asked the National Academy of Sciences to assess the execution of the MAR and compare its promised benefits to its actual impact. The resulting report, *The National Weather Service Modernization and Associated Restructuring: A Retrospective Assessment*, concluded that it was a success. The key challenges now faced by the NWS are (1) keeping pace with accelerating scientific and technological advances, (2) meeting expanding and evolving user needs in an information-centric society, and (3) partnering with an enterprise that has grown considerably since 2000. This report presents recommendations for the NWS to address these challenges, with a more agile organizational structure and workforce, putting it on a path to become second to none at integrating advances in science and technology in its operations and meeting user needs, leading in some areas and keeping pace in others.

NAE member **John A. Armstrong**, retired vice president for science and technology, IBM Corporation, chaired the study committee. Paper, \$38.00.

Sustainable Development of Algal Biofuels. Biofuels made from algae are gaining attention as a domestic source of renewable fuel. However, with current technologies, scaling up production of algal biofuels to meet even 5 percent of US transportation fuel needs could create unsustainable demands for energy, water, and nutrient resources. Continued research and development could yield innovations to address these challenges, but determining whether algal biofuel is a viable fuel alternative will involve comparing the environmental, economic, and social impacts of algal biofuel production and use to those associated with petroleum-based fuels and other fuel sources. This report was produced at the request of the US Department of Energy.

NAE members on the study committee were **Donald L. Johnson**,

retired vice president, Product and Process Technology, Grain Processing Corporation, and **Gregory Stephanopoulos**, Willard Henry Dow Professor of Biotechnology and Chemical Engineering, Massachusetts Institute of Technology. Paper, \$64.00.

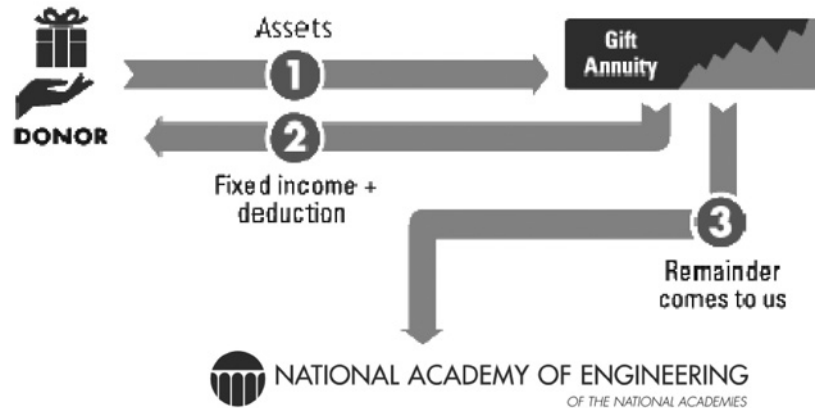
Science for Environmental Protection: The Road Ahead. The US Environmental Protection Agency asked the National Research Council to assess the agency's capabilities to develop, obtain, and use the best available scientific and technologic information and tools to meet persistent, emerging, and future mission challenges and opportunities. The committee determined that tensions inherent to the structure of EPA's work contribute to persistent challenges faced by the agency, and meeting those challenges will require devel-

opment of leading-edge scientific methods, tools, and technologies as well as a more deliberate approach to systems thinking and interdisciplinary science. The report outlines a framework for building science for environmental protection in the 21st century and identifies key areas where enhanced leadership and capacity can strengthen EPA's abilities to both address current and emerging environmental challenges and take advantage of new tools and technologies to address them.

NAE members on the study committee were **Joan B. Rose**, Homer Nowlin Chair in Water Research, Fisheries and Wildlife Department, Michigan State University, and **Jerald L. Schnoor**, Allen S. Henry Chair Professor, Department of Civil and Environmental Engineering, The University of Iowa. Paper, \$48.00.

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