PREPARING FOR THE FUTURE

Prologue

The world is changing at a pace that in many ways challenges understanding and adaptation. Many changes result from advances that improve life, while major problems persist that affect people the world over. What is the role of engineering in both addressing existing problems and leading progress and well-being into the future as we navigate our rapidly changing world?

The National Academy of Engineering (NAE) began thinking about engineering for the 21st century in 2006, when it invited a distinguished, international committee chaired by former defense secretary William Perry to opine on what engineering needs to achieve in this century. While it is not possible to predict what engineering will create in the 21st century, the committee set out to predict what engineering needs to create for all people based on current understanding. The predicted needs led to its vision for engineering in this century. After receiving thousands of inputs from around the world on this needs question, in 2008 the committee’s NAE report articulated its engineering vision, which can be stated in 15 words:

Continuation of life on the planet, making our world more sustainable, secure, healthy, and joyful.

This is the first and only time that such an all-encompassing vision for the entire planet has been articulated for engineering. The vision is not tied to specific creations or things; nor does it focus on organizations or countries. Rather, it points clearly to the need for engineering to serve all people everywhere by advancing our world in four ways: sustainability, security, health, and joy of life.
But a vision statement alone is not enough. The committee members then turned their attention to identifying a minimum set of specific goals whose solutions everywhere would deliver the vision. They proposed 14 goals, termed the *Grand Challenges for Engineering*. These Grand Challenges include problems that must be solved to ensure our long-term survival on the planet—making solar energy economical, sequestering atmospheric carbon, preventing nuclear terror. They also include advances that will make our lives more joyful and fulfilling—enhancing virtual reality, advancing personalized learning, engineering the tools of scientific discovery.

The Grand Challenges encapsulate what engineering needs to deliver to all people on the planet in the 21st century, and, as described below, they are launching a movement that could transform our world. For students and the public alike, they provide the clearest and most compelling answers to the questions: What is engineering? How does it serve people and society? The Grand Challenges for Engineering speak to an impulse that is universal and timeless and also to the essence of engineering: creations serving people and society.

**The Grand Challenges Scholars Program**

In 2009 three top administrators at US engineering schools recognized that the Grand Challenges—which are global, complex, multidisciplinary, and deeply embedded in society—offer a new way to organize and galvanize engineering education. The engineers who will undertake the challenges will need comparably sophisticated and multidimensional skills and understandings because the scopes of the challenges are global. These administrators concluded: If this is the direction of engineering in this century, should we not prepare students graduating today for global problems like these grand challenges?

The result was their proposal of the Grand Challenges Scholars Program (GCSP), which, through grassroots support from students, faculty, and administrators, is spreading throughout the United States and around the world. It is a unique, student outcome–based supplement to any engineering program that prepares students to undertake global, engineering systems–like initiatives. Because its focus is on five student competencies only, and not the administration or conduct of a program, any university or college can adopt the GCSP supplement into its own program. The five student competencies are:
i) **Talent Competency**—mentored research/creative experience on a Grand Challenge–like topic

ii) **Multidisciplinary Competency**—understanding the multidisciplinarity of engineering systems solutions developed through personal engagement

iii) **Viable Business/Entrepreneurship Competency**—understanding the necessity of a viable business model for solution implementation, preferably developed through experience

iv) **Multicultural Competency**—understanding cultural differences to ensure cultural acceptance of proposed engineering solutions, preferably developed through multicultural experiences

v) **Social Consciousness Competency**—understanding these engineering solutions should primarily serve people and society.

Note that the talent competency (i) is the only one referencing the Grand Challenges for Engineering directly. The remaining four prepare students for global initiatives by expanding their national engineering program to a global one. The talent competency can be directed as needed.

These competencies are particularly attractive to women and minorities, who constitute over half the students in Grand Challenges Scholars Programs. The GCSP attracts students because it prepares them for real and urgent problems that need solutions; it is a basis for realistic experiments, homework, and design challenges during their undergraduate years; and it offers a clear view to future jobs and opportunities in engineering.

Participating universities have the autonomy to create the supplemental GCSP using their strengths and resources to instill the five competencies without altering their existing engineering program. Each institution is responsible for its GCSP, selecting the students, educating them, determining their development of the competencies, and deciding how to recognize their achievement. GCSP students graduate with both the desire and the ability to make a difference in the world. As of March 5, 2018, 122 US and 34 international universities have implemented or are preparing their independent GCSPs.
The Global Grand Challenges Summits

In addition to the launch of the GCSP there has been a groundswell of interest in the Grand Challenges outside the United States. This international enthusiasm led the NAE, the Chinese Academy of Engineering (CAE), and the UK Royal Academy of Engineering (RAEng) to hold the first Global Grand Challenges Summit (GGCS) in London in 2013, followed by a second summit in Beijing in 2015 and a third in the United States in 2017. The next will be hosted by the RAEng in London in 2019.

The three summits have brought together leaders of companies, universities, and governments with researchers, administrators, and students to foster collaboration, elaborate on the vision, and motivate innovative thinking in engineering. More broadly, the summits highlight and explore engineering efforts toward achieving the Grand Challenges with the aim of highlighting advances made on the individual challenges, inspiring engagement on the challenges by the next generation of change makers, and sparking global collaborations among the participants.

On July 18–20, 2017, the third and largest Global Grand Challenges Summit was held in Washington, DC on the campus of George Washington University. Nearly 900 people attended, half of them undergraduate or graduate students from 150 universities/colleges. With a dynamic, wide-ranging focus on the Grand Challenges for Engineering, the summit featured plenary talks, technical presentations, discussion of educational programs, and efforts and opportunities to inform the public. Onsite activities to engage students were held before, during, and after the summit. The talks and presentations, discussions, student activities, and associated events are described in these proceedings.

The organizers offer their profound appreciation for generous support provided by Lockheed Martin Corporation, Boeing Company Charitable Trust, Northrop Grumman Foundation, and Shell Oil Company.
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WELCOME REMARKS TO THE THIRD GLOBAL GRAND CHALLENGES SUMMIT

The quest to solve the Grand Challenges for Engineering “is a movement, not a project,” said C. D. Mote, Jr., president of the US National Academy of Engineering (NAE). “No one is in charge, but all of us are pulled in by the idea.”

With these words, Mote welcomed almost 900 people—along with a worldwide video audience in the thousands—to the 2017 Global Grand Challenges Summit. Held July 18–20 in Washington, DC, and sponsored by Lockheed Martin, The Boeing Company Charitable Trust, Northrop Grumman Foundation, and Shell, the summit was the third in a series inspired by the NAE’s 14 Grand Challenges for Engineering issued by an NAE committee in 2008. The first summit was held in London in 2013, the second in Beijing in 2015. Jointly organized by the NAE, the United Kingdom’s Royal Academy of Engineering (RAEng), and the Chinese Academy of Engineering (CAE), the summits aim to inspire the innovation, education, and cooperation needed to meet the Grand Challenges and ensure the survival of life on Earth. “The idea is bigger than any of us, but at the same time we can all be part of it,” said Mote.

NAE chair Gordon England observed in his opening address that the second day of the summit was the 48th anniversary of the first man to step on the moon, and to mark the...
occasion astronaut Jack Fischer welcomed participants to the summit in a taped address from the International Space Station. The Grand Challenges were designed to advance the goals of people around the globe, he said, but they also are a source of inspiration for this and future generations of engineers, and it is inspiration that fuels the engine of innovation. “From all of us on the International Space Station, best wishes for a summit that ignites ideas, inspiration, and initiatives that will solve the Grand Challenges.”

Breakthroughs at the frontiers of science and technology have brought disruptive changes to the world, noted Zhou Ji, president of the Chinese Academy of Engineering, in his welcoming remarks. Accompanying these changes are significant challenges in areas such as climate change, energy security, food security, cybersecurity, poverty eradication, public health, and terrorism. Engineering is the engine that will solve these problems, Zhou said. By fostering innovation, economic growth, development, and collaboration, engineering can “create a better future for all nations.”

David Thomlinson, international secretary of the Royal Academy of Engineering, particularly welcomed the students in attendance, who accounted for half the participants. “The challenges we will be discussing will require the talent, ingenuity, and leadership of the next generation of engineers,” he said. All engineers, and especially those just entering the profession, should view the Grand Challenges as opportunities to work on some of the most important problems of our time, to diversify the profession, and to develop a more prosperous world for all. “The Grand Challenges movement is reframing what it means to be an engineer and equipping students with the skills necessary to rise to those challenges.”

Mote pointed out that a number of activities associated with the summit—before, during, and after—were specifically designed for students: the FIRST (“For Inspiration and Recognition of Science and Technology”) Global robotics challenge, a student business model competition, a How to Save the World podcast competition, a poster session, and a student-sponsor networking event.

“This summit is an investment in your future, but in fact it is an investment in everyone’s future,” Mote told the students, because everyone’s future will depend on the work done by engineers.
“Throughout human history, engineering has driven the advance of civilization,” said Rajiv Shah, president of the Rockefeller Foundation, in the first of four keynote presentations. Engineering and science have been at the vanguard of global efforts to end extreme poverty and extreme suffering around the world. They have been the defining characteristic of development, national competitiveness, and global problem solving. They make it possible to imagine a world in which children no longer die from preventable causes before their fifth birthday or go to bed hungry at night.

Shah, whose father was first an aerospace and then an automotive engineer, said that he has seen the power of engineering to improve human life throughout his career. As administrator of the US Agency for International Development from 2009 through 2015, he headed an organization that has made a difference in the lives of millions of people by applying the products of engineering to fight hunger and disease. “Witnessing the agony and suffering of famine is something you will never forget,” he said. “In Afghanistan and Somalia, I’ve heard the cries of children afflicted by chronic hunger and hidden malnutrition. I’ve had the personal honor to hold some of these children in my arms. There’s nothing quite so morally powerful and painful as watching a child perish because we didn’t have enough technology and science and engineering and political will applied in the right context to save that child’s life.”

When he became president of the Rockefeller Foundation, Shah spent time in the foundation’s archives to learn about the organization’s impacts. For more than a century, the foundation has been applying science, technology, and engineering to improve the state of humanity, he observed. It supported the development of treatments for diseases like hookworm and yellow fever, helped create the field of public health, funded agricultural research that
has removed nearly a billion people from the brink of starvation, and leveraged the expertise of engineers, architects, and designers to rebuild cities after natural disasters in a more resilient form.

Yet many challenges remain, exacerbated by the advances of automation, globalization, and political retrenchment. Science and engineering have contributed to the development of many of these challenges, Shah acknowledged: The cyclotrons that the Rockefeller Foundation funded in the 1930s to study the atom were also crucial instruments in the development of nuclear weapons. The creation of a worldwide digital communications network has created the potential for cyberattacks. Rapid advances in machine learning, automation, and artificial intelligence are transforming the workplace but may displace workers in entire sectors of the economy.

Whether the application of new technologies turns out well or disastrously depends on decisions being made right now, Shah said. Too many engineers have left the moral and social dimensions of the problems they are tackling to politicians and corporate executives. “I would urge you not to be moral bystanders; instead, be moral leaders,” he said. “The world needs more engineers like you, more experts with evidence-based worldviews who can help make technological advances work for the poor, feed the hungry, and bring power to those who live without.”

Consider working for nonprofit and public sector organizations, Shah encouraged the young people at the summit. “Building drones for a defense contractor is certainly more lucrative than doing the same to capture the agricultural outcomes in rural Kenya, but I guarantee you that the work and the results that you can deliver in people’s lives [in Kenya] will be infinitely rewarding.”

Engineering can continue to be a force for profound good. “I challenge you to be the ones who think of how that can be done, to take what you’ve thought about and what you’ve learned here and be ambassadors wherever you go for how engineering can be harnessed to improve the state of humanity. As long as you do that, you can’t go wrong—and I can’t wait to see what you’re going to achieve.”
RISING TO THE CHALLENGES

Even familiar technologies, when applied in creative ways, can have profound effects on human life, said Deng Zhonghan, cofounder, chair, and chief executive officer of the Chinese technology company Vimicro and a member of the Chinese Academy of Engineering.

Over the past three decades the number of cars in China has soared from 10 million to 190 million, which has contributed to severe air pollution problems in the country. But bicycles, which used to be a major mode of transportation in China, are making a comeback.

With a new generation of on-demand, shared bicycles offered by several companies, riders use their cellphones to find and unlock nearby bikes, which they can ride to a destination and then leave for subsequent users. The bikes have become so popular all over China that the market for them jumped from 2 million units in 2015 to 20 million in 2016.

“China is now ‘reinventing’ the bicycle,” Deng said. The system consists of much more than the bicycles. It relies on an extensive infrastructure of cellphones, wireless technologies, satellites, cloud computing, and other technologies, and Deng explained that the country is well prepared to provide this infrastructure.

China has more than a billion cellphone and mobile internet users. It has some of the largest software and hardware companies in the world. It has the second largest economy in the world after the United States and has become the largest manufacturer of many industrial and consumer products. It has the world’s largest highway and rail systems. All are the products of engineers, scientists, and technologists who have helped China become the modern country it is today, he said.

The interdependencies of bike-sharing programs demonstrate one of the essential features of the Grand Challenges, Deng pointed out. They are systems problems. Solving them will require input from many sectors, including...
public policy, law, international relations, the social sciences, and the broader culture.

Particularly problematic are the challenges involving food, energy, and other natural resources. The conventional development model characterized by widespread mass production, consumption, and waste has contributed to severe environmental problems even as it has addressed human needs. “How can a high quality of life and security be sustained and extended worldwide in this century?” Deng asked. “This is not a national question or a business question. It is a question that concerns everyone on this planet.”

The Grand Challenges capture the global dimensions of the problems humanity faces. “We are all humans living and breathing together on the same planet of seven billion people,” said Deng. “We have more in common than differences, [and this] needs to be emphasized over and over again. Any problem divided by seven billion becomes minuscule, while any progress multiplied by seven billion becomes a giant achievement.”

More than 2,000 years ago, the Chinese philosopher Confucius expressed the idea that “the greatest road is for all under heaven,” said Deng. Today, this can be interpreted as a call for a community of common destiny that encompasses all of humanity. The idea of “all under heaven” connotes “the sense of a joint responsibility to work together, to help each other, to share the burden.”

The Third Global Grand Challenges Summit brought together some of the best minds in the world. “When we have a higher purpose, we will be empowered to awaken the deepest hope in our hearts,” Deng concluded. “Let’s roll up our sleeves and work hard.”

**THE ORIGINS OF THE GRAND CHALLENGES**

The Grand Challenges for Engineering were inspired by a 2003 NAE report titled *A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives*. That report “gained wide recognition,” observed Alec Broers, a member of the UK House of Lords, in his keynote remarks. “If you picked it up, the chances are you wouldn’t put it down for an hour or so.”

But reflecting on the accomplishments of engineering inevitably raised the question of challenges that remain—including those caused by rapid technological advances. That recognition contributed, in 2006, to the creation of an NAE committee charged with identifying “the world’s grand challenges and opportunities—specifically, those that might be addressed with...”
“The Grand Challenges for Engineering were chosen because of their diversity and because they will all improve the quality of life throughout the world. And they have stood up extremely well to the test of time.”

With input from NAE members, alumni of the NAE’s Frontiers of Engineering program (which is for engineers 30–45 years old), engineering societies, and the public, the 18-member international committee, of which Broers was a member, identified 14 Grand Challenges for Engineering in 2008. “These are not necessarily the top 14 challenges,” said Broers. “They were chosen because of their diversity and because they will all improve the quality of life throughout the world. And they have stood up extremely well to the test of time.”

Twenty Transformative Engineering Accomplishments of the 20th Century

- Electrification
- Automobile
- Airplane
- Water supply and distribution
- Electronics
- Radio and television
- Agricultural mechanization
- Computers
- Telephone
- Air conditioning and refrigeration
- Highways
- Spacecraft
- Internet
- Imaging
- Household appliances
- Health technologies
- Petroleum and petrochemical technologies
- Laser and fiber optics
- Nuclear technologies
- High-performance materials
Solving any one of the problems would have profound effects. Some are related to making the world a more joyful and fulfilling place, such as advancing personalized learning and enhancing virtual reality. Some are related to making human societies more resilient against natural and human threats, such as improving urban infrastructure and securing cyberspace. And some must be solved to enable human beings to survive on this planet.

The engagement of the world’s brightest young people will be essential if the challenges are to be met, Broers continued. This aspect of the challenges led to the creation of the Grand Challenges Scholars Program, in which students work on problems in the spirit of the Grand Challenges to develop competencies in five areas:

- Creativity and research skills through mentored experiences on Grand Challenge–like topics
- Multidisciplinary understanding gained through experience with systemic problems
OPENING UP ENGINEERING TO ALL

The fourth and final keynote took the form of a conversation between moderator Ali Velshi, television anchor of MSNBC Live, and Martha Lane Fox, who cofounded Europe’s largest travel and leisure website and serves in the UK House of Lords. A focus of their conversation was an issue that arose throughout the summit: how to get more women involved in engineering and in information technology industries in particular.

The promise of the Internet was that it was going to enable new voices to be heard, new businesses to be created, and different people to have the technology to empower their lives, said Fox. “It’s surprising that, in a sector that did not exist 30 years ago, we have replicated the old hierarchies so quickly,” she observed. The percentage of women in the UK House of Lords is higher than the percentage of women working in Internet-based companies, where

- Business and entrepreneurial skills leading to viable business models for implementation
- Multicultural understanding that can be implemented in intended cultures
- Social consciousness that serves people and society

The Grand Challenges Scholars Program is “off to a strong start,” said Broers, with established and planned efforts in 18 countries. There is now growing interest in disseminating the program much more widely and using it to attract a diverse array of students to engineering. “The message is spreading around the world,” Broers concluded. “We must all ensure that it continues to do so.”
only about 4 percent of the people writing code are women. “I find that very disappointing,” she said.

Fox and Velshi both drew a contrast with the summit, where women were well represented among the student participants, perhaps because of the way the Grand Challenges frame engineering.

Women need to be encouraged to pursue engineering at all levels of their education, Fox observed. But she made the case that education alone is not enough, because it does not work quickly enough. Engineering needs to change its practices to be more open to women. When a job listing for a programmer or software engineer simply lists the required credentials, women are far less likely to apply than if the listing describes the problem to be solved.

For their part, women need to talk about their successes in engineering as a way of drawing more women into the profession. “If you are a young woman in STEM [science, technology, engineering, math], talk about the work you’re doing,” Fox said. “The technology industry is filled with some extraordinary people who want to hear from diverse voices but sometimes don’t know how to find them.”

The Grand Challenges require that as many people as possible be involved in creating solutions. “I encourage everyone in this audience to feel that they can participate and address the big things that we are going to have to think about as humans, whether it’s climate change, the mass movement of people, or poverty.”

One prominent need is for more technically trained people to be involved in government,
Fox said. “I’m sure there are people in this room who care deeply about public policy, about public service, and want to improve the lives of citizens.” Having such people in government positions, even if just for a few years, she said, would reduce the gap between the pace of innovation and the policies that are needed to channel that innovation in positive directions.

The Internet is entering its adolescence, and many people are starting to ask, “What have we unleashed on the world?” noted Fox. The Internet needs to have a moral compass, she argued, part of which involves striving for a more equitable world. Business leaders need to be thinking about the ethics of their actions, and legislative and regulatory frameworks need to reinforce ethical principles. The default position should be that the Internet is “free, accessible, and inclusive for all…. We should be striving to make sure that everyone has the capacity to use this power.”

VIRTUAL REALITY

“The reality we experience is a construct in our minds based on highly incomplete data,” according to Michael Abrash, chief scientist at Oculus VR. By providing the proper perceptual inputs, virtual reality technologies can produce “whatever experiences we want, and those experiences will feel real.” Someone using these technologies can teleport anywhere in the world, interact with anyone anywhere and from any time period, and experience an infinitely varied digital universe. “That’s my vision of how virtual reality can change the world,” he said.

But vast challenges must be solved for virtual reality to become a key part of how people work, play, and interact with each other, he added. World-class multidisciplinary work on vision, audio, and touch is needed for virtual reality to advance. How humans sense, reconstruct, and understand the world needs to be understood.

The creation of human avatars in a virtual world is particularly promising, said Abrash, because “people are the most interesting things in the world to other people.” But our innate
sensitivity to human nuance makes the creation of virtual humans one of the biggest challenges in virtual reality research.

Virtual reality has already found many applications—medical training, architectural design, education, playing games, and watching movies—and its future applications are limitless, especially as prices drop. “We are capable of building an interface to the digital world that lets us interact using a significant fraction of the full bandwidth and biological processing that we’re evolved for.” Virtual reality is not just a platform, he concluded. It is a way to provide all the functionality that humans expect out of life.

DEEP LEARNING

Deep learning can solve real-world problems that cannot be solved any other way, said Jeffrey Dean, leader of the Google Brain team. It uses the technology of neural networks to extract information from raw, heterogeneous, and often noisy data to develop increasingly complex representations of the information while learning to accomplish a task.

In the past, computational power limited the advance of neural networks and deep learning, but leaps in computer power are bringing new capacities. Today, deep learning neural networks can classify images, convert audio signals to transcripts, translate from one language to another, and derive descriptions from images. “Computers have gone from not being able to see to being able to see” because of these technologies, said Dean. As the technologies progress, flexible general purpose artificial intelligence systems are an obvious goal.

Deep learning could make major contributions in solving all the Grand Challenges. It could help restore and improve urban infrastructure by enabling autonomous vehicles to convert raw sensory data into situational understanding, thereby reducing accidents and traffic. It could advance health informatics by answering difficult healthcare questions and improving diagnosis and treatment plans. It could help reverse engineer the brain by reconstructing neural circuits from high-resolution images of thinly

Right: Jeffrey Dean of Google explores the concept of deep learning
Below: A student asks a question with a special microphone box
sliced brain tissue. It could engineer the tools needed for scientific discovery—for example, Google’s TensorFlow system is an open source platform for expressing machine learning ideas and systems that results in executable representations of machine learning algorithms.

Deep learning will be used as a tool to solve problems across many domains, Dean predicted. “If you’re not considering how to use deep learning to solve your problems, you probably should be.”

BIOMATERIALS

Throughout human history, people have used natural materials to help repair the body, said Molly Stevens, professor of biomedical materials and regenerative medicine at Imperial College London. The Maya used seashells to replace missing teeth—the nanoscale structure of the shells allowed the material to integrate into the jawbone. When ophthalmologist Harold Ridley discovered that plastic shards of Spitfire canopies embedded in the eyes of World War II pilots were inert, he used the polymer material to develop the first intraocular lenses, which are now implanted in millions of people around the world. “It started from the observation that you could have a material that would be inert and could provide this function within the body,” Stevens said.

Today, one focus of regenerative medicine is tissue engineering, where active materials work to repair the body. For example, stem cells can be cultured on a scaffold and then used to repair damaged tissues or organs. According to Stevens, virtually every organ and tissue type is now being studied to apply this approach. However, the task is dauntingly complex. Each tissue and organ requires different materials and engineering strategies, because different tissues repair themselves differently. Complex biological and chemical interactions make procedures difficult to translate to the clinic.

With biomaterials and tissue engineering, there is “a really big opportunity for engineering to have an impact on health.”
Biomaterials also can be used to monitor activities within cells. For example, hundreds of tiny needles can interact with stem cells and deliver molecules to the cells at different points. This and related technologies could have many possible applications, including early detection of disease and monitoring for infections. Similarly, nanoparticles inserted into the body can interact with cells to detect biological states and combat disease.

Close collaborations between engineers, biomedical researchers, and clinicians are essential in this work, Stevens observed. “This is a really big opportunity for engineering to have an impact on health.”

**ANTIBIOTIC RESISTANCE**

Sally Davies, chief medical officer for England and chief medical advisor to the UK government, invited engineers to work with medical professionals on a specific problem: drug-resistant infections. “Imagine a world where you had a caesarean section or a hip replacement and it killed you,” she said. “We’re getting to that stage…. The bugs are beginning to bite back.”

Natural selection means that mutations in bacteria, viruses, or fungi that provide resistance to drugs will spread, either through an organism’s progeny or through lateral transfer of the mutations among organisms. The increased use of antibiotics in humans and animals intensifies selective pressures, thereby heightening the problem. Inappropriate use of drugs to treat diseases can foster resistance without commensurate improvements in health. Fish and livestock excrete 70 to 90 percent of the antibiotics they are given into the environment, further increasing human exposures.

Today, one person dies every 45 seconds around the world because of a drug-resistant infection. By 2050 the toll could reach one person every 3 seconds, which would have a massive effect on the global economy.

Engineering can make vital contributions to solving this problem, Davies said. Among many promising innovations are mobile early warning systems for infectious diseases, smart biomaterial surfaces and dressings, novel drug delivery strategies, techniques to prevent the transmission of drug-resistant microbes, and interactive tools that can inform the public about antimicrobial resistance. The problem “needs all communities working together,” she said. “With these wicked problems, only by collaboration will we get it right.”
GLOBAL CLIMATE CHANGE AND SUSTAINABLE CITIES

Atmospheric greenhouse gas concentrations, global temperatures, and risks to human populations are all increasing, stated Ding Yihui, academician of the Chinese Academy of Engineering and professor and special advisor on climate change for the China Meteorological Administration. Among the greatest of these risks are

- extreme weather and climate events
- failure to mitigate and adapt to climate change
- large-scale loss of biodiversity and collapse of ecosystems
- large-scale natural disasters
- anthropogenic environmental damage and disasters.

To achieve sustainable development and equity, including the eradication of poverty, the risks posed by climate change must be limited, Ding said.

China is prepared to meet the targets laid out in the Paris Agreement, he reported. The country is planning for its carbon emissions to peak before 2030 and is entering an era of low-carbon emissions and green energy development. It is increasing its use of wind and solar energy, nuclear power, and hydroelectricity to achieve sustainable development and management of the economy. Already, China is the largest producer of renewable energy in the world, and its emphasis on renewable and low-carbon sources of energy is growing.

The world faces two contrasting futures, according to Ding: a peaceful, secure, and sustainable society, or an irreversibly degraded and disastrous society. Engineers will help determine which of these futures is realized. “The responsibility of engineers is huge in our future,” he said.

A crucial aspect of this future will be continued urbanization, said Wu Zhiqiang, vice president of Tongji University and professor in the College of Architecture and Urban Planning. When he was a student in the 1970s, less than 20 percent of the Chinese population lived in cities. That figure is now 57 percent and is on the way to a projected 80 percent—a reversal from what it was less than half a century ago. Wu reported that 30–50 million people each year are moving from the countryside to cities in China. “Children
born after 1990 all want to leave the countryside. Their dream is to live in the city.”

The rapid pace of urbanization requires changes in technology, infrastructure, and ways of living. Food distribution networks are needed to feed growing urban populations. Educational systems must provide new city dwellers with the skills they need to find work and prosper. Environmental pollution, flooding, traffic congestion, and the growth of slums all need to be addressed.

Most important, continual innovation will be needed to make cities both fulfilling and sustainable, Wu said. He and his colleagues have developed models of urban centers that incorporate such factors as housing, industry, services, commerce, and transportation to explore how cities will need to change to accommodate their growing populations. These models then can be used to guide decisions by policymakers and the work of engineers.

Cities are evolving entities in which different systems interact in complex ways. Continued urbanization will require “innovation for all,” Wu said. “That’s what people wish, and that’s what we should do.”

REVERSE ENGINEERING THE BRAIN

The human brain has more than 1,000 different types of cells, and “to understand the brain, we must understand the connectivity, the behavior, and the genes expressed” by these different cell types, said Christof Koch, president and chief scientist at the Allen Institute for Brain Science. Beneath each square millimeter of cortex—the outermost layer of the brain, which is a sheet roughly the size of a 15-inch pizza—lie 100,000 neurons, meaning that the cortex alone contains roughly 16 billion neurons. Altogether, the brain’s neurons make 200 trillion connections with each other.

The human brain is “the most complex, most highly organized piece of excitable matter in the known universe,” said Koch. It “gives rise to our intelligence, our ability to speak, to see, to reason, and our conscious experience of the world.”

The Allen Institute uses a range of techniques to examine and better understand neurons both in human brains and in the brains of mice. For example, researchers are using genetic engineering to turn neurons on and off with beams of light and detect their interconnections; analyzing and modeling the electrical signals neurons use to communicate with each other; and studying the genetic expression patterns and development of different neuron types. The ultimate goal, said Koch, is to combine all these technologies to get a complete view of the brain.

The result will be a greatly enhanced ability to translate basic research into therapies for disease and disability through neuroengineering. These therapies can be either noninvasive or invasive. Noninvasive therapies act from outside the skull to perform diagnoses or therapeutic interventions. Invasive therapies, based on subdural or intracranial technologies,
can be much more targeted to specific brain regions and even specific cells. Such therapies have taken the form of cochlear and retinal implants, deep-brain stimulation for Parkinson's patients, and reconstitution of lost functionality in neurological or psychiatric patients.

“This is a very exciting time,” Koch concluded. “We’ve learned more about the brain over the last ten years than we have in the last thousand. We are on the road to understanding how the 16 billion neurons in our cerebral cortex give rise to who we are.”

Rikky Muller, cofounder of Cortera Neurotechnologies, Inc., and a faculty member at the University of California, Berkeley, described a miniaturized and minimally invasive brain interface that she has helped develop. A thin, flexible, biocompatible chip is implanted on the surface of the cortex and powered by a wireless connection that can send and receive information. The device can monitor brain activity on a small scale and stimulate neurons on the basis of that activity, allowing therapy to be tailored to the individual and to that individual's mental state. The mission of the company she cofounded to commercialize the technology is “to make a significant patient impact, especially for neurological conditions,” she said.

The technology still requires substantial development to take advantage of its tremendous potential, Muller said, but existing versions of the device provide researchers with more information about how the brain works, creating a self-reinforcing loop through which future versions can be improved.

**GRAND CHALLENGES SCHOLARS PROGRAM**

“I had no idea what engineering was until I went to college,” said Kushal Seetharam, a graduate of the Grand Challenges Scholars Program at Duke University. “If you had given me a real-world problem to figure out with a high degree of success, I would not have known where to start….

The Grand Challenges scholarship was a great way to approach that type of thinking and instill that research-focused perspective in my mind.”

As a Grand Challenges scholar, Seetharam, who went on to a graduate program at the Massachusetts Institute of Technology in theoretical physics and quantum computing, worked on a sanitation system for developing countries, field testing it in Togo. He and a partner developed a business plan for the project, and he also taught at a local high school, where he tried to bring in the Grand Challenges thinking to his students.

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Challenges. His undergraduate experiences encompassed the five competencies of the Grand Challenges Scholars Program: the development of research skills, multidisciplinary understanding, entrepreneurial skills, multicultural understanding, and social consciousness.

The Grand Challenges Scholars Program was founded by Thomas Katsouleas, provost at the University of Virginia; Richard Miller, president of Olin College of Engineering; and Yannis Yortsos, dean of the Viterbi School of Engineering at the University of Southern California. Its objective, said Katsouleas, is “to prepare students with the skill set and mindset needed to tackle the Grand Challenges.” Almost 50 such programs were active at the time of the summit, more than 120 deans from across the United States have committed to creating Grand Challenges Scholars Programs of their own, and the program has spread to Singapore, Malaysia, Hong Kong, and Australia, with other countries expressing interest in joining. The number of graduates from Grand Challenges Scholars Programs is rapidly approaching 1,000—and approximately half of them are women.

Amara Uyanna was attracted to the program because it “broadened my horizons on the endless opportunities available to me as an engineer and propelled me to step outside my STEM comfort zone.” A chemical engineering graduate of the program at Louisiana Tech, Uyanna researched thermal energy storage devices, worked with another student to develop a prototype of a device, did an internship at ConocoPhillips in Houston, tutored K-12 students, and took interdisciplinary courses in sociology, psychology, and other subjects.

Since beginning her work on a master’s degree in global policy studies and innovative economics at the University of Texas, Austin, she also has worked with the nonprofit organization Sustainability International on the cleanup of the Niger Delta, where decades of oil spills have created great human hardship. These experiences have taught her that engineers must understand not only the technical aspects of a problem but also the “people part of things” so that policies can “better merge the two.”
Aaron Gordon led the creation of the Grand Challenges Scholars Program at Clemson University after being introduced to the program while visiting colleges in high school. The Clemson College of Engineering was willing to put people, logistics, and resources behind the program, and Gordon and a few other engineering students recruited freshmen on “Grand Challenge Day” and had them participate in engineering activities to learn about the program.

As a Grand Challenges Scholar, Gordon, who has gone on to a graduate program in civil engineering at Georgia Tech, helped manage engineering projects in Haiti that involved improving water systems, latrines, aquaculture facilities, and schools. The GCSP can “define your college experience,” he said.

Ellen Chisa seconded that observation. “One of the great things about the Grand Challenges Scholars Program is that it motivates students to go into engineering because they see what they can do.” During her time as a Grand Challenges Scholar at Olin College of Engineering, she worked on a learning management system for middle schoolers to maintain their interest in mathematics and science courses.

In the middle of her MBA program at Harvard Business School, Chisa took a leave to serve as chief executive operating officer of a startup company that handles the infrastructure involved in building software products. She remained involved in the Grand Challenges Scholars Program by reviewing the portfolios of new students, providing them with feedback, and helping them think about the problems they are trying to solve.

GLOBAL STEM CHALLENGES PROGRAM

The Grand Challenges have been inspiring educational innovation not only at the college level but in precollege education as well. Fairfax County Public Schools in Northern Virginia have established the Global STEM Challenges Program at Thomas A. Edison High School in Alexandria as a way to integrate science, mathematics, technology, and computer science education. The program starts in ninth grade with 90 students who work on problems related to food, after which the same cohort works together on water-related problems in the tenth grade and energy-related problems in the eleventh grade. They take other subjects with the full student body while having access to resources provided through the program, including a fabrication laboratory.

With traditional STEM instruction, “students did not see the connections between the curriculum and the real world,” said Pamela Brumfield, principal of Edison High. In the Global STEM Challenges Program, students work in groups on real-world problems,
developing their communication, critical thinking, and problem-solving skills.

Students are not used to failure in traditional STEM classes, Brumfield observed; “success” is a function of learning the material and regurgitating it on tests. But failure is an essential part of problem solving, and this is a lesson that parents have to learn as well. “Parents very often want to protect their children from any kind of failure,” she said. “We had to educate parents who have children participating in the program.”

Establishing the program required extensive coordination with the Virginia Department of Education, the Fairfax County school system, science and mathematics coordinators, and individual teachers, said Scott Settar, who is the manager for science, technology, engineering, the arts, and mathematics (STEAM) integration in the school system. The program is not a magnet program and is open to all students. It therefore has to prepare those who will go on to four-year colleges as well as students who choose different paths. “That’s one thing we wanted to demonstrate—that all students can be successful.”

Teachers were extensively involved in designing and establishing the program, observed Katherine Shirey, a program officer for the Knowles Teacher Initiative (Knowlesteachers.org). Teachers worked with experts on curricular integration who could help them incorporate the new approach in their classrooms. Knowles Senior Fellows from her organization partnered with Fairfax County teachers to plan units of instruction around the themes of food, water, and energy and continued working with the teachers to help them implement the curriculum. The planning and collaboration assist teachers with these broad issues and the Grand Challenges while leaving day-to-day curricular details to the teachers.

Francis Reyes, a student in the first cohort of the program, got a new perspective on STEM fields. “In a regular classroom, I felt myself working more by myself,” she said. “In STEM class, you work and progress as a team.” Teachers also have a different relationship with students in the Grand STEM Challenges Program. “The teachers won’t baby you,” Reyes said. “They ask, ‘Why do you think that’s the answer,’ or ‘How did you get to that conclusion?’ It better prepares you to be assertive.”

The result is a different way of thinking, she said. “The way I think now is more what people are looking for. If I wanted to start working somewhere, I feel that I’m more prepared.”
ENGAGING THE PUBLIC

When Deanne Bell was working as a mechanical engineer after graduating from Washington University in St. Louis, she heard about a television audition for engineers. “I’m totally not qualified for this,” she told herself, “but they want an engineer, so why not.” Today she is host of the CNBC show Make Me a Millionaire Inventor, which helps aspiring inventors and entrepreneurs answer such questions as: How do I build my first prototype? How do I develop a business plan? Who would be an investor who would be a good fit to launch my business?

“We need to do so much more as engineers to communicate our passion and our love for engineering,” said Bell. “We need to get out into the media more and share our passions, particularly with women.”

Education is one essential step to get more girls into engineering, but so is the everyday environment. When girls see Bell on television, they may realize that they, too, can be an engineer. And “it doesn’t have to be television,” she said. “All of you can start your own blog, become an influence on social media, and share your love for science and technology.”

Engineering is one of the best foundations a young person can have for any career, said Bell. Engineers can apply their education and experience to whatever interests them. “If you are really passionate about policy, then use that foundation to bring engineering into the conversation. And if you don’t have a seat at the table, make a seat at the table.”

Senator Tim Kaine of Virginia agreed. “The best legislators I’ve served with were not people who were experts in politics before they decided to get into politics. They were engineers, they were surgeons, they were innovators. If you are at all interested in politics and public service, master an expertise other than politics and bring it into politics.”

Engineers bring far more than their technical knowledge to their other endeavors, Kaine added. Being a success in the workplace requires a large variety of skills, including communication, problem solving, creativity, flexibility, teamwork. “Sometimes people call those soft skills. Folks, those aren’t soft skills. They’re survival skills, and they’re every bit as important as technical mastery.”
Another way to engage the public with engineering is to bring the excitement and inspiration of sports and entertainment to science, technology, and engineering. Inventor and entrepreneur Dean Kamen founded the organization FIRST (“For Inspiration and Recognition of Science and Technology”) in 1989. This year, FIRST will serve more than a million young people (ages 6 to 18) in nearly 100 countries.

FIRST was established to ignite a global passion for STEM fields by having teams design and build robots to participate in what Kamen calls “coopertitions”—events that combine competition and cooperation.

“Politics is about dividing the world,” said Kamen. “Technology is uniting the world. We have to show kids from all over the world, at a young age, that if they have the common language of math and science, they can all be on the same side of the team fighting the same issues.”

Student Business Model Competition

The day before the summit, 15 teams of undergraduate students—five teams each from the United States, United Kingdom, and China—met to engage in a student business model competition. Each team presented a seven-minute business proposal to address one of the Grand Challenges to a panel of seven judges. Andrea Belz, vice dean for technology innovation and entrepreneurship at the Viterbi School of Engineering at the University of Southern California, coordinated the event.

In the final session at the summit, Rod Makoske, senior vice president of corporate engineering, technology, and operations at Lockheed Martin, praised the student participants for their dedication, enthusiasm, hard work, and professionalism. Lockheed Martin knows “firsthand the importance of education,” he said. “We hire about 3,000 engineers, technologists, and mathematicians for our programs and research and development labs every year. Our future success and global well-being depend on a constant supply of highly trained, highly capable technical talent.”
He presented prizes to the top three teams:

- Third Prize ($5,000): “Dream House,” developed by Bao Yizheng, Gao Yufang, Huo Jingyong, Ji Chunyu, Mou Qun, Sun Xiaqing, Wang Lifeng, and Xi Huixia of Shanghai University

- Second Prize ($10,000): “MoreWater,” developed by George Huish, Sean Irving, Jessica Mountfield, Andrew Petty, Mike Thundow, and Sam Watkins of Bournemouth University

- First Prize ($25,000): “Worldcare Technologies,” developed by Allison Duchnak, Martin Hartel, Kirk Hutchison, Christopher Liu, Yajur Maker, and Caitlyn Smith of the University of California, San Diego

Student Networking and Poster Competition

Students had opportunities throughout the summit to network with each other and with other participants. One such opportunity was a lunchtime session in which students presented posters related to research on the 14 Grand Challenges for Engineering. Winners were chosen in three categories—originality, impact, and design—for both undergraduate and graduate groups.
The undergraduate winners of the Student Poster Competition were:

- **Originality:** “Ultra Clean: An ultrasonic & vacuum wear-free washing machine” by Shida Zheng of China

- **Impact:** “Nomadic resource generation” by Cristovao Mario Cacombe, Daniel Kokocinski, Joao Martins Nunes, Morgan Pierre-Mitchell, and Ali Younessi of the United Kingdom

- **Design:** “Point-of-care health informatics for proactive epilepsy seizure alert” by Stefan Manoharan of the United States

Students with the winning posters received $2,000 each.

The graduate winners of the Student Poster Competition were:

- **Originality:** “Network design for in-motion wireless charging of electric vehicles in urban areas” by Mamdouh Mubarak of the United States

- **Impact:** “Virtual reality enhanced intelligent upper-arm exoskeleton for rehabilitation of stroke patients” by Rana Soltani-Zarrin of the United States

- **Design:** “Encapsulated biomaterial-enabled microsensor for pancreatic health monitoring” by George Banis of the United States

Students with the winning posters received $2,000 each.
How to Change the World

Before, during, and after the summit, over 150 students took part in the How to Change the World podcast challenge run by University College London’s Department of Science, Technology, Engineering, and Public Policy. With help from an expert teaching team from University College London and visiting experts, small and diverse teams of students interviewed experts and created video or audio podcasts on connecting the Grand Challenges to real-world problems. Using raps, interviews, formal presentations, and live discussions, the students covered topics ranging from clean water access to public engagement to eco-friendly digital technologies.

Bethany Gordon, an engineering student at the University of Virginia, won the competition with her podcast on how engineers can improve people’s lives. By showing how engineers could use virtual reality to experience life in a temporary home in a shipping container in rural Armenia, which suffered a catastrophic earthquake in 1988, she proposed that engineers from around the world could collaborate remotely to crowd-source practical solutions to humanitarian crises.

A podcast by Yun Gu (Peking University) and Katie Brown (Auburn University) on the barriers to women entering the engineering profession and how to overcome those barriers was selected as runner-up. Gordon, Gu, and Brown will receive financial support to attend the next Global Grand Challenges Summit, to be held in London in 2019.

Listen to the top ten podcasts at https://www.ucl.ac.uk/steapp/professional-education/ggcs-how-to-change-the-world.
Although women continue to be significantly underrepresented in STEM-related fields, over 60 percent of the teams that participated in the 2017 challenge were organized, founded, or led by women. “For me as a girl it’s a really big thing to be in this, because there aren’t many girls in technology right now,” said Paola Rwizihirwa from the Rwandan team.

In March the teams received robotics kits with all the necessary mechanical, electrical, and software components needed to assemble a robot, divided into a “build component” and a “programming component.” They worked on their robots using only the parts provided.

“It was a lot of trial and error,” Ali Anver of the Sri Lankan team told the website ReadMe.

Her teammate Ishini Gammanpila elaborated: “Whenever we solved the problems in one stage and moved on to the next stage, we had to go back to the drawing board and restart from scratch. This was because new problems...”
always arose when we moved on to each stage. And when we fixed these new problems, the old problems suddenly returned."

Although the creation process can be full of roadblocks, sometimes these barriers lead to moments of inspiration. Ryan Benschop of the Guyana team described how they found the design for their robot: "After spending weeks tinkering and reshaping, hoping that this and that design worked, we thought of a similar problem, which was already solved in our local environment." Guyana’s coastline is stabilized by an elaborate system of kokers, which sluice water through gated channels. The team visited several kokers and studied the design and mechanics behind each one. "Upon realizing that the very mechanisms and parts which allowed the koker to be lifted were in our own robot kit, we immediately began working on a similar system," said Benschop. "This pull-up system worked perfectly and never failed us during the competition."

Kamen founded FIRST to inspire leadership and innovation in science, technology, engineering, and mathematics. "By inspiring the bright young minds of tomorrow through STEM, countries all over the world, particularly developing countries, could experience accelerated economic growth, and obtain secure and peaceful livelihoods for their nations," he said. Participants in the games learn that challenges can be overcome through teamwork, communication, and cooperation.

As Joe Sestak, president of FIRST Global, concluded, “The world’s greatest power is the power to convene, to bring nations together in the pursuit of a common goal, proving that what we have in common is far grander than what sets us apart.”
At lunch on the final day of the summit, participants brainstormed about how to spread the Grand Challenges both at the local level and on a global scale. From these discussions emerged a “top 11” list of what Thomas Katsouleas, executive vice president and provost at the University of Virginia, termed “great ideas.” “Our charge to you now,” he said, “is to take them back with you and implement them.” Katsouleas cofounded the Grand Challenges Scholars Program in 2009 with Richard Miller, president of Olin College of Engineering, and Yannis Yortsos, dean of the Viterbi School of Engineering at the University of Southern California.

For students, faculty members, and administrators who want to start a Grand Challenges Scholars Program, Jenna Carpenter, founding dean of engineering at Campbell University, recommended starting with the program’s website (www.grandchallengescholars.org),

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**Ideas for Future Actions to Spread Engagement in the Grand Challenges**

1. Develop online open courses, Ted Talks, and simulation games around the Grand Challenges
2. Engage professional organizations
3. Include more countries
4. Use the Grand Challenges to promote diversity
5. Engage corporate leaders in support of the Grand Challenges
6. Include ethics in the five components of the Grand Challenges Scholars Program
7. Incorporate the Grand Challenges in education curricula and framing
8. Develop a comprehensive media platform to reach the public
9. Use the Grand Challenges to change your conversations about what engineering is
10. Start a Grand Challenges scholarship program at your school
11. Be ambassadors—share what you learned here about the movement with students and colleagues
which includes step-by-step instructions for getting started. Carpenter and other members of the program’s steering committee are eager to serve as sources of information and feedback and as mentors for program organizers.

Yortsos observed that the Grand Challenges Scholars Program has been growing rapidly as the problems at the heart of the program continue to capture the attention and interest of engineers and policymakers around the world. “It’s an example of how a network of institutions forms and grows,” he said. The NAE Grand Challenges and the Grand Challenges Scholars Program constitute “a fundamental tool by which we can change the conversation about engineering.”

Miller added that the National Academy of Engineering, with support from a number of sponsors, has taken the initiative to create a full-time staffed office specifically in support of a network for program participants.

The Grand Challenges are poised to expand in all dimensions, especially as they continue to attract the attention of students who want to change the world. “We’re going to need the best and brightest young people in America and across the world to commit,” said Miller. “The education of the next generation to deal with the Grand Challenges is itself the overarching challenge that we face.”
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