The 2016 Annual Meeting of the National Academy of Engineering Grand Challenges Scholars Programs

PREFACE

The 14 Grand Challenges for Engineering identified in 2008 by a committee of the National Academy of Engineering (NAE) may seem disparate:

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

Yet they are united by underpinning a defining vision: Continuation of life on the planet, making our world more sustainable, secure, healthy, and joyful.

The Grand Challenges for Engineering also provide a central unifying vision for education. Efforts to address the Grand Challenges develop the expertise and knowledge that schools, universities, and businesses say they need and want. The Grand Challenges require work that is collaborative, interdisciplinary, multicultural, and business oriented. They are socially conscious, since their goal is about continuing life on this planet. They enable students to cultivate higher-order skills such as synthesis, teamwork, and contextualizing. They help create confident engineering leaders ready to address the most pressing global issues of the 21st century.

There has never before been a global vision for engineering. The United Nations Sustainable Development Goals are directed toward particular segments of the population, whereas the Grand Challenges are goals that extend beyond the United States, beyond the developed or developing worlds, to everyone on the planet. They are a framework for creating solutions to the problems of all people, all aspects of society, everywhere. To date their solutions have not been driven by federal, philanthropic, or private funding but have depended on the inspiration of individuals, organizations, and the public at large.

The Grand Challenges Scholars Program was created in 2009 by deans of engineering Thomas Katsouleas (then at Duke University) and Yannis Yortsos (University of Southern

California) and Richard Miller (president of Franklin W. Olin College of Engineering). Its goal is to inspire students in every country and culture and prepare them to undertake contributions, if not careers, dedicated to addressing the Grand Challenges. The Program identifies five competencies that each student must attain to achieve designation as a Grand Challenges Scholar:

1. Research/creative—Experience with mentored research or projects related to the Grand Challenges
2. Multidisciplinary—Understanding gained through experience with the multidisciplinary dimensions of the Grand Challenges
3. Business/entrepreneurship—Understanding gained through experience with the business models needed to solve the Grand Challenges
4. Multicultural—Understanding gained through engagement with cultural issues
5. Social consciousness—Attainment of deeper social consciousness and motivation to address societal problems, often gained through service learning

Each college and university that participates in the Grand Challenges Scholars Program determines both how and whether its students achieve these five competencies through their educational program and experiences. The competencies may be part of the regular academic curriculum or acquired in other ways, as determined by each student and institution.

Already nearly 40 colleges and universities have instituted Grand Challenges Scholars Programs, and in 2015 more than 122 deans of engineering—about a third of all the engineering deans in the United States—signed letters to President Obama committing themselves to graduating 20,000 Grand Challenges Scholars within ten years. When I presented these letters to the president, he said, “I’m 200 percent behind it.”

Grand Challenges Scholars Programs are also under way in Australia, Botswana, China, Egypt, Hong Kong, India, Kuwait, Malaysia, and Singapore. In June 2016 I presented a plenary lecture on the program at the annual meeting of the Chinese Academy of Engineering to inspire it to join the NAE in promoting the program globally. Later in 2016, I described the program in a plenary address to 1,500 deans of engineering and others from 70 countries at the annual meeting of the World Engineering Education Forum and the Global Engineering Deans Council in South Korea. In short, interest in the Grand Challenges Scholars Program is rapidly growing nationally and internationally.

On October 6–7, 2016, the first annual meeting of the Grand Challenges Scholars Program brought together its three founders with about 100 students, teachers, administrators, policymakers, and others interested in the program’s promise and future. Participants exchanged information, discussed experiences and plans, and formed personal and virtual connections. They also identified best practices, ways to build momentum, areas in need of programmatic support, and measures to ensure the success, effectiveness, and sustainability of this visionary program.

I extend sincere thanks to Richard Miller, Yannis Yortsos, Thomas Katsouleas, Jenna Carpenter of Campbell University, Joe Hughes of Drexel University, Yevgeniya Zastavker of Olin College of Engineering, Randy Atkins of the National Academy of Engineering, and Peter Kilpatrick of the University of Notre Dame, who organized the meeting and moderated its panels. I also thank Tom Kalil and the staff of the Office of Science and Technology

Policy, who hosted the second half of the meeting at the Old Executive Office Building and described the overlap between the program's goals and national objectives.

The Grand Challenges Scholars Program has thus far been driven at the grass-roots level without a centralized organization or financial support. National and global expansion calls for coordination of grass-roots efforts to develop new programs, benefit from successful program designs, and document the influence of the movement, and governments can play a role in this coordination.

This is a unique moment in history for the Grand Challenges Scholars Program. A program like this has never existed before. It could transform not just the experiences of students but the characteristics of entire institutions and of the society in which those institutions are embedded.

The Grand Challenges Scholars Program encapsulates our hopes and needs for the future.

C. D. Mote, Jr.
President, National Academy of Engineering

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Status of the Grand Challenges Scholars Program

Points Highlighted by the Speakers

- The Grand Challenges Scholars Program has the potential to transform engineering education.
- To address the Grand Challenges, students need to integrate knowledge across technical and nontechnical domains, develop entrepreneurial skills, and acquire expertise in global and social issues.
- The skills developed by Grand Challenges Scholars are the skills businesses want in their employees, and include multidisciplinary problem solving, the ability to work in teams, and a focus on the real-world feasibility of solutions.
- Recruiting and building community among students builds motivation and persistence and attracts a more diverse population to engineering.
- The Grand Challenges Scholars Program can knit together existing resources on campuses and in communities to create new opportunities for students and institutions.

Yannis Yortsos, dean of the Viterbi School of Engineering at the University of Southern California and chair of the organizing committee, opened the 2016 annual meeting of the Grand Challenges Scholars Program, which was held October 6–7 in Washington, DC.[1] He described the program as "the blueprint for the future of engineering education" and "a model program on how to advance engineering education in this country."

The Grand Challenges Scholars Program links K–12 schools with colleges and universities and with the workplace, and this linkage will be essential to make the world more sustainable, safe, healthy, and joyous. "Educating the generation that will have to save the world is a daunting but exciting challenge," said Gregory Washington, dean of the University of California, Irvine. The Grand Challenges Scholars Program offers a way to meet that challenge, representing "the next logical progression in the education of our students," Washington said. "We are basically moving from engineering science, to engineering analysis, to engineering design, and now to engineering synthesis, because the Grand Challenges incorporate all of the above."

The first panel briefly summarized the status of the program and then described how it works at three institutions: Arizona State University, Bucknell University, and the Georgia Institute of Technology. In a final panel presentation, a representative of Dassault Systèmes spoke about the many connections between the program and the private sector.

[1] The meeting agenda is in appendix A.

Pull quote: "We are moving from engineering science to engineering analysis to engineering design, and now to engineering synthesis, because the Grand Challenges incorporate all of these."

TOWARD THE TRANSFORMATION OF ENGINEERING EDUCATION

The 2004 NAE report *The Engineer of 2020* pointed out that the engineers of the future will work on very different problems than have past engineers.[2] New problems will arise in fields such as nanotechnology, information technology, and bioengineering, and they will involve complex social and ethical challenges. The report made the case that a transformation of engineering education will be necessary to solve these problems and meet these challenges.

A year later, the companion report *Educating the Engineer of 2020* offered recommendations on how to achieve this transformation.[3] It called for enriching and broadening the educational experiences of engineers, and preparing them to integrate knowledge across multiple technical and nontechnical domains.

The release of the *Grand Challenges for Engineering* in 2008 outlined a way to achieve the necessary transformation of engineering education, said Jenna Carpenter, dean of engineering at Campbell University, who moderated the first panel at the meeting.[4] Solving the Grand Challenges will require that new engineers have creativity, entrepreneurial skills, and expertise in global and social issues. Existing curricular and cocurricular programs will need to be adapted to help students achieve broader skill sets, and new initiatives must be undertaken, she said. All students—including those currently underrepresented in engineering—will be needed to solve the Grand Challenges.

However, time is short to make the necessary changes. "The engineers of 2020 arrived on our campus about two months ago," noted Carpenter. "The transformational educational experience that they are supposed to have is more or less what we have right now."

The current number of Grand Challenges Scholars is relatively small, but the program is growing rapidly. As of the 2016 annual meeting, 287 Grand Challenges Scholars had graduated from 14 programs. But by the end of 2016, Carpenter said, 50 programs were scheduled to be active, and deans from 122 institutions had signed letters to President Obama committing themselves to the program. The pledge of these institutions to produce 20,000 Grand Challenges engineers in the next decade may seem "a long way to go," Carpenter acknowledged, but with 122 participating institutions, an average of only 17 graduates a year is needed. "It is very much an achievable goal."

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[2] National Academy of Engineering. 2004. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington: National Academies Press.

[3] National Academy of Engineering. 2005. *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. Washington: National Academies Press.

[4] National Academy of Engineering. 2008. *Grand Challenges for Engineering*. Washington: National Academies Press.

BUILDING A LARGE PROGRAM AT ARIZONA STATE UNIVERSITY

The Grand Challenges Scholars Program at Arizona State University (ASU) is a striking example of the ways the program could expand. The ASU program focuses on building a community of scholars in which students receive the support that they need to succeed, said Amy Trowbridge, director of the program at the university. An optional summer program before their freshman year brings 40–50 students to campus for a week to connect with other students, faculty members, and staff. When students arrive at ASU for their first year, many have already been invited and possibly accepted into the Grand Challenges Scholars Program.

From their first days on campus, the more than 100 Grand Challenges Scholars in each class are encouraged to develop plans for completing the program. They take a required interdisciplinary course to get a jumpstart on identifying their interests, and are mentored by faculty advisors for each engineering discipline. Research stipends or experiential learning grants enable students to interact not only with the network of scholars on campus but with other Grand Challenges Scholars around the world. And a student-led organization helps build community and reaches out to connect with industry.

These steps have increased student engagement, retention, and the number of students who complete the program. "The students are excited," said Trowbridge. "They're achieving more exciting things and accomplishing greater things than they would have on their own."

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BROADENING AND DEEPENING ENGINEERING EDUCATION AT BUCKNELL UNIVERSITY

The Grand Challenges Scholars Program at Bucknell University has about 50 students, said T. Michael Toole, program director and professor of civil and environmental engineering. He focused his remarks on two classes developed for students in the program.

The first-semester Foundation Seminar, open to all students interested in the Grand Challenges Scholars Program, presents fundamental topics that they probably will not get in their standard engineering courses but that are important for understanding the Grand Challenges. For example, they are exposed to critical perspectives on technology, microeconomics, finance, public policy, management, and the diffusion of innovations. The course, with just 16 students, brings in experts from local industry or across campus and features ongoing interactions with faculty members. It is embedded in the society and technology residential college, where students live with other students who are pursuing similar interests.

At the end of the semester, students complete a 5,000-word essay on an independent research project. Some of them are concerned about that requirement, Toole acknowledged, but the college provides scaffolding, process management, feedback, and research assistance to help them accomplish it, and the project often leads to further research down the line.

The second course Toole described is for upperclassmen on exploring the Grand Challenges. The first time it was offered, it was called Entrepreneurship and Renewable Energy in Iceland: the students studied management, finance, public policy, and renewable

energy—and spent ten days in Iceland, where they toured geothermal, hydro, and biofuel plants. The next time it was called Social Entrepreneurship in New Orleans and was cotaught by Bucknell's director of civic engagement and service learning, who has taken students to New Orleans for service learning trips many times. After courses on finance, social entrepreneurship, public policy, and the geology of New Orleans, students travelled to the city to engage in service and social entrepreneurship.

"In engineering we often talk about T-shaped engineers, [who have] both breadth and technical depth," said Toole. In Bucknell's program the Grand Challenges students achieve breadth and depth on humanitarian issues. He described them as "totally committed to civic engagement."

Pull quote: Bucknell's Grand Challenges students achieve breadth and depth on humanitarian issues and are "totally committed to civic engagement."

WELCOMING A BROAD RANGE OF STUDENTS AT THE GEORGIA INSTITUTE OF TECHNOLOGY

The Georgia Institute of Technology takes a particularly inclusive and egalitarian approach to program recruitment and enrollment, welcoming students with grade point averages ranging from 2.7 to 4.0. "Some of you who are more cynical might be mindful of the adage that *A* students become your colleagues, *B* students become your bosses, and *C* students become your donors," said Gary May, dean and Southern Company Chair in the College of Engineering at Georgia Tech. "That may be true, [but] that's not why we do this."

Georgia Tech invites students with lower GPAs to distinguish themselves by designing and assembling a rich portfolio of connected academic and off-campus experiences. It seeks to prepare them to be "fearless learners and solution creators as opposed to problem solvers."

The Grand Challenges program flips the paradigm for engineering education. Rather than focusing on how to solve a differential equation using a Laplace transform, the students learn *why* solving the equation is important: to address a Grand Challenge.

The program emphasizes cross-cultural encounters. These can be achieved through international experiences—and more than half of undergraduate engineering students complete their degrees with an international experience, said May—but they can also take place locally. At Georgia Tech, Grand Challenges Scholars might work with immigrant workers, low-income youth, or the elderly, "as long as the project engages them in a meaningful way with another cultural group." In the Atlanta area, students can work with the Georgia Refugee Community, the Latin American Association, CARE, or dozens of other groups.

Georgia Tech offers students a global engineering leadership minor, which seeks to give them problem-solving, solution-creating, leadership, and interpersonal skills as well as cross-cultural competence and exposure to the Grand Challenges. These students also complete a related internship or an international capstone experience.

The program is strongly aligned with industry, urban partnerships, and entrepreneurial activities. Because Atlanta is an innovation hub in the Southeast, May predicts that the Grand Challenges Scholars Program at Georgia Tech "will become a nucleus for bringing together industry partners, city and state leaders, [and] Georgia Tech faculty,…researchers, and undergraduate scholars to form a consortium of mutually minded innovators."

Most of the components of the program already existed at Georgia Tech before the institution formally joined the initiative. Interdisciplinary curricular opportunities are widespread, more than a third of the school's undergraduate students do research, and more than 100 freshmen live and work together in the Grand Challenges living-learning community, working in cross-disciplinary teams on projects that often extend beyond their freshman year. The institution's Create X initiative has already helped to launch 42 student startups; and the Vertically Integrated Projects (VIP) program has large groups of undergraduate and graduate students working on problems that extend the academic design experience beyond a single semester, up to three years.

The integration of the Grand Challenges Scholars Program into what is an already active learning environment "is a natural fit for us at Georgia Tech, and one that we expect to flourish," May concluded. In fact, with more than 9,000 engineering students at the institution, he predicted that the program will have no trouble achieving its goal of 150 graduates per year.

Pull quote: Georgia Tech's Grand Challenges Scholars Program seeks to prepare students to be "fearless learners and solution creators as opposed to problem solvers."

ALIGNING INTERESTS AT DASSAULT SYSTÈMES

The Grand Challenges Scholars Program "aligns strongly with our vision as a company to make an impact in the world," said Al Bunshaft, senior vice president of global affairs at Dassault Systèmes. The program "embodies the types of characteristics that will create the employees that we want to hire today and in the future."

Every ten years the company develops a decadal vision for the company, Bunshaft explained, and the most recent vision called for creating products "that harmonize product, nature, and life." For example, using an integrated set of tools for multidisciplinary problems, the company is conducting projects in collaboration with universities focused on goals such as creating the solar-powered aircraft that recently circumnavigated the world. Another visionary project is called Ice Dream, which involves towing an iceberg from the North Atlantic to North Africa to be a source of freshwater. The company did "a complete feasibility study, with a very diverse team of individuals, to prove that this in fact could be done," said Bunshaft. These kinds of projects are particularly attractive to young people.

Dassault Systèmes is located near Olin College of Engineering and for years has sponsored senior capstone projects with the college. It also has funded affordable design and entrepreneurship programs. In one, for example, a team of students worked on developing a grater for cassava to be used by women in Ghana, for whom grating cassava is a complex and manually intensive task. They developed a portable machine that could be manufactured locally and "reduced the time for this [task] by 85 percent," said Bunshaft.

These kinds of projects galvanize students and the company's employees alike. They motivate young people, both in universities and in the private sector, because of the impact they make in the world. They are especially effective in attracting a more diverse population to science and engineering, such as women, who are drawn to societal problems more than to purely technical problems.

In addition, partnerships can link the work going on in universities to future focus areas in industry. “Often the work that you pioneer becomes the work that we try to commercialize,” Bunshaft observed. For example, Dassault Systèmes often hires students who worked on joint projects. “There’s no better look we can get on future talent than working together on a program or bringing students in for internships.”

The Grand Challenges Scholars Program inculcates the kinds of skills engineers need to be effective where they work, said Bunshaft, such as multidisciplinary problem solving, team-based problem solving, and a focus on the real-world feasibility of solutions. “We’re very much behind this, and we’re very excited to collaborate with a number of you in these programs. We think you’re absolutely onto something, not only…about saving our planet for future generations but more—I’ll say selfishly as an industry participant—about creating the types of future engineers and scientists and employees that we require.”

Pull quote: The Grand Challenges Scholars Program inculcates the kinds of skills engineers need to be effective at work—multidisciplinary and team-based problem solving, and a focus on the real-world feasibility of solutions.

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Student and Alumni Experiences

Points Highlighted by the Speakers

- The Grand Challenges Scholars Programs allows students to find meaning in what they do by bridging the personal and the professional.
- The Grand Challenges Scholars Program can connect students both with their communities and with problems of global importance.
- Working on problems associated with the Grand Challenges can immerse students in environments outside their colleges and universities.
- Establishing a supportive community of scholars can help students recognize the value of the program's components.

One great asset of the Grand Challenges, said Yevgeniya Zastavker, associate professor of physics at Olin College of Engineering and moderator of the meeting's second panel, is that they are a set of diverse problems that attract diverse students at diverse institutions. As a result, the program tends to attract more students who have been underrepresented in engineering in the past. Then, "we just need to give them opportunities and scaffolding, step away, and let them do the magic that they do," said Zastavker.

The second panel featured brief presentations by six current or former Grand Challenges Scholars. All said that the program has been as transformative in their lives as it could be for engineering education in general.

A PASSION FOR SUSTAINABILITY AND CLIMATE CHANGE AT ARIZONA STATE UNIVERSITY

In the introductory course for the Grand Challenges Scholars Program at ASU, Kaleigh Johnson discovered the field "that has become my passion—sustainability." After hearing presentations from a series of guest speakers, students were asked to write a 1,500-word paper on an emerging technology related to one of the fields described. The technology Johnson chose was industrial biotechnology, and specifically the use of biological systems to manufacture chemicals, fuels, and materials.

"I was captivated by the idea of using microbes and sustainably producing materials that are essential to everyday life. It seemed to me such a simple and elegant concept of solving the complex challenge of reducing human impact on the environment." For the previous eight months, Johnson, a senior completing her fourth and final year of chemical engineering at ASU, had been doing research with the goal of using *E. coli* to produce a compound more efficiently and with lower resource consumption than current production methods.

Her experience with research helped her earn a place on the Fulbright Commission's Summer Institutes program, in which she spent a month at the University of Exeter studying climate change issues. "This was a life-changing experience for me," she said. "Not only because it was my first time on a plane and my first time out of the country, but also because it gave me an incredible opportunity to see how another country was working to solve the Grand Challenges while engaging in discussions with students from around the world."

While on the fellowship, she took peat samples to analyze carbon storage, measured tree trunks to determine biomass, and created climate models based on atmospheric composition trends. "It was a great opportunity for me to gain valuable knowledge on climate change, and it gave me an international perspective on the Grand Challenge theme that I hope to impact throughout my career."

Johnson, whose experience with research has convinced her to pursue a PhD in chemical engineering, also praised the summer institute at ASU, which gets students excited and motivated toward completing the program. Service learning activities also provide students with opportunities related to the Grand Challenges program.

To improve the program, she said that work could be done to improve the program's success in inspiring the global engineering leaders of tomorrow. "Perhaps the biggest challenge that I've seen these programs face is in establishing a supportive community of scholars to prevent students from losing sight of the value of its components." To build community, she helped lead the student organization at ASU that gives students opportunities to socialize with one another and connect with industry.

*Pull quote: "*I was captivated by the idea of using microbes and sustainably producing materials that are essential to everyday life. It seemed to me such a simple and elegant concept of solving the complex challenge of reducing human impact on the environment.*"*

ENGINEERING TOMORROW'S INFRASTRUCTURE AT LOUISIANA TECH UNIVERSITY

When he was growing up in Shreveport, Louisiana, Kendall Belcher's parents sent him to many STEM-related activities. One was a conference at Olin College of Engineering, where the principal civil engineer behind the World Trade Center spoke of the importance of civil engineering. "That presentation laid the foundation for my wanting to be a civil engineer," he said.

When he enrolled at Louisiana Tech University, he knew immediately that he wanted to be a Grand Challenges Scholar, "and I chose the challenge of restoring and improving urban infrastructure." According to the American Society of Civil Engineers, US infrastructure overall earns a D. "This is a catastrophe," said Belcher. "Infrastructure provides us with access to the world through information, communication, and travel."

In addition to his studies, Belcher started a recycling program at the university that received tremendous support from the community, local officials, and other students, so much so that it was eventually adopted by the community. And he worked on a solar-powered water purifier for underdeveloped countries, which was entered in a business plan competition at the Global Grand Challenges Summit.

Belcher received his bachelor's degree in civil engineering at Louisiana Tech in 2013 and stayed to continue his graduate studies. His research focuses on reducing downward deflection of rehabilitated bridges in Oklahoma to improve bridge performance, design, and service life.

As a teaching assistant, he emphasizes the importance of understanding engineering concepts and being able to apply them in real-life situations. "Safe and reliable infrastructure can improve our quality of life and lessen our environmental footprint. Through research, effort, and time, I will use my Grand Challenges and STEM experiences to do exactly that."

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REAL-WORLD IMPACTS OF ENGINEERING AT DUKE UNIVERSITY

More solar energy falls on the surface of the Earth in a single hour than all the energy humanity uses in an entire year. "That is why my Grand Challenge is making solar energy economical," said Lauren Shum, a senior at Duke University. Her research on thin-film organic solar cells is compelling for two reasons, she said: (1) they are made of earth-abundant materials, and (2) in contrast to silicon-based solar cells, they are inexpensive and do not require much energy to manufacture. While they are not yet as efficient as solar cells, "they are gaining in efficiency as quickly as silicon did when it was new," she said.

This research has given her more context for real-world engineering experiences than any of her classes could have, she observed. "Being a Grand Challenges Scholar makes me think about the long term, the future, and the social impact," and the program has extended that context to the broader world, she said.

Shum has participated in an innovation challenge involving poverty in rural Madagascar, where 81 percent of people are malnourished and impoverished. "In the spirit of the Grand Challenges Scholars Program, my thoughts drifted back to solar energy." Her team, which included students studying neuroscience and public policy, pitched a passive solar pasteurization process for spurring dairy markets and bringing better nutrition and more income to the people of rural Madagascar. Shum planned to use the project for the entrepreneurship component of the Grand Challenges Scholars Program.

Shum reflected that her experiences have extended well beyond engineering. "By explicitly declaring these interdisciplinary areas—the global component, the entrepreneurship component—as inherent to the engineering experience,…we prepare engineers to be more ready and more impactful for the real world."

Pull quote: "Being a Grand Challenges Scholar makes me think about the long term, the future, and social impact."

BUILDING BRIDGES AT THE UNIVERSITY OF IOWA

Nate Weger, a junior in mechanical engineering at the University of Iowa who has been involved in the Grand Challenges Scholars Program since the end of his freshman year, described it as "a defining feature of my experience at the university. When I first came to college, I had 1,000 things I wanted to do and no idea how to start. I wanted to see new places and meet new people and change the world. Through the Grand Challenges Scholars Program, I was able to make this a reality."

His most significant project, he said, has been with Bridges to Prosperity, a nonprofit organization whose mission is to reduce poverty associated with rural isolation through the construction of pedestrian bridges. The summer after his freshman year Nate traveled to Nicaragua to help a rural community with an annual flooding problem. They raised funds for, designed, and built a bridge to provide residents access to necessary services. "This was the first time in my life that I saw firsthand the positive impact that science and engineering can have on other people's lives."

Since then he has become a drone pilot, flown in a helicopter to improve flood mapping, and helped develop a system to monitor water levels in rivers around Iowa. Right before the meeting, he coordinated an effort to get 50 university students to Cedar Rapids to help with sandbagging in the city's second worst flood in recorded history. He has put together a group of 20–30 students twice a year to help clean up and reduce erosion in the creeks and rivers around Iowa City.

For the research portion of the Grand Challenges Scholars Program, he worked on improving the use of biomass gasification for clean energy. For the future, he is looking into the use of biochar, a byproduct of the gasification process, to scale up gasification systems and enhance carbon sequestration.

"The Grand Challenges Scholars Program has had an amazingly positive impact on my college experience," he said. "It has pushed me to do things I never imagined myself doing, and I am definitely a better person and student because of that."

Pull quote: "This was the first time in my life that I saw firsthand the positive impact that science and engineering can have on people's lives."

ENGINEERING BETTER HEALTH AT THE UNIVERSITY OF SOUTHERN CALIFORNIA

For Stephanie Fong, who graduated from the University of Southern California with a bachelor's degree in biomedical engineering and a master's degree in mechanical engineering, participation in the Grand Challenges Scholars Program included research, study abroad in France and Australia, and volunteering. But the highlight of the program was her involvement in a global entrepreneurship project that combined engineering and biomedicine.

Fong, an athlete, had previously fractured her spine, and an innovative medical device was critical to her recovery. "I chose biomedical engineering because I want to transform lives in the same way that a device changed mine."

In her junior year she took a course on innovation for business and engineering majors in a global context. Students shared a virtual classroom with students from India, South Korea, China, and Israel; collaborated with partners around the world through video chats; and traveled to Israel at the end of the class to meet and work together in person. "I discovered how to create

robust designs and meaningful value propositions and then scale those up to an internationally sustainable business."

Those skills came full circle in her master's year, when she united these business principles with the drive to create global medical solutions. With another engineer and a business student, she helped develop Flex Specs, continuously adjustable eyeglasses that can change the power of the lens with a turn of a dial. "We realized that there was a great worldwide need for accessible vision care." Their project won first place and a $15,000 grant in the Min Family Engineering Social Entrepreneurship Challenge, which provides USC students with the opportunity to use innovations in engineering and technology to develop sustainable and effective solutions to global problems. The team is using the funding to secure a patent and become a full-fledged social enterprise.

The Min Family Challenge also got the students involved in local communities in Los Angeles, where they interviewed consumers for their product within a two-mile radius of USC. "It's easy to do engineering in a vacuum where you're trapped on campus and you're studying in the library, but you can go a few blocks from campus and interview people and make a difference in their lives."

In addition to continuing her work on Flex Specs, Fong has begun working for a company that develops critical care and heart valve technology. Her job has already taken her to Puerto Rico and Ireland to visit suppliers.

"It's challenging for recent graduates to move from academia to industry," she said. "Often new hires lack exposure to business paradigms. It's essential for university education to reflect real-world problems, and I strongly feel that my GCSP exposure will give me a unique advantage in launching my career. My hope is that Grand Challenges institutions will continue to champion global entrepreneurship and develop students into world-facing leaders."

Pull quote: "I discovered how to create robust designs and meaningful value propositions and then scale those up to an internationally sustainable business."

PURSUING SOCIAL JUSTICE AT OLIN COLLEGE OF ENGINEERING

The first experience Celina Bekins, a junior at Olin College of Engineering, had with the Grand Challenges Scholars Program was an ideation session in the first semester of her freshman year. Using butcher paper and Sharpie pens, students brainstormed project ideas related to the Grand Challenges themes of sustainability, security, global health, and joy of living.

"Sitting there I realized, 'Why wait to start doing good?'" she recalled. "I was talking about starting *that semester* on a project that could impact the world. I thought, 'Getting started now would give me time to make mistakes and learn while surrounded by supportive, like-minded, and similarly passionate people.'"

In her sophomore year she learned that she could join her passion for social justice with her technical work. She had been volunteering as a peer advocate for sexual respect. "I realized that I wanted to work within the joy of living theme on a self-designed project ending sexual violence and human trafficking."

She began shaping her education to fit with her interests. In her software design class, for example, she worked with a team of students to create a data visualization system for campus

security and safety statistics across the country. Her plan for the rest of her time at Olin includes classes on design for activism, with a focus on understanding people and designing systems to meet their needs.

"My experiences with GCSP have played an integral role in shaping my education," she said. Reflection is a large part of the Grand Challenges Scholars Program at Olin, where each scholar completes a reflective portfolio that connects their Olin experiences with their Grand Challenges work. "I've used this idea of reflection to shape my own path even as I walk down it," she said. "Although sexual violence and human trafficking are imposing transdisciplinary issues, Olin's GCSP has helped me find ways to begin tackling the issue, and I know I have the tools and support I need to make a difference."

Pull quote: "I realized, 'Why wait to start doing good?... Getting started now gives me time to make mistakes and learn while surrounded by supportive, like-minded, and similarly passionate people.'"

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Links to K–12 Education

Points Highlighted by the Speakers

- The Grand Challenges can be used as an organizing principle for everything from individual projects and classes to entire schools and school systems.
- Students can use the Grand Challenges to partner with individuals and organizations outside their schools.
- The Grand Challenges provide a way to link K–12 and higher education.
- A unified national effort could provide K–12 teachers with the professional development they need to teach engineering.

Students benefit from learning about engineering and the Grand Challenges as early as possible, said Randy Atkins, senior program officer for media/public relations at the National Academy of Engineering, who moderated the third panel of the meeting. "Kids are motivated by making a difference, and the Grand Challenges are an important tool to do that," he said. Schools across the country are introducing and using the Grand Challenges with high school, middle school, and even elementary school students. In doing so, they are "breaking down the silos around courses using the biggest issues of our time," said Atkins.

The third panel of the meeting featured K–12 teachers and administrators who have been directly involved with the use of the Grand Challenges in their schools.

ORGANIZING AROUND THE GRAND CHALLENGES AT THE WAKE STEM EARLY COLLEGE HIGH SCHOOL

The Grand Challenges "are not a program we do," said Jennifer Parker of the Wake STEM Early College High School in Raleigh, North Carolina. "The Grand Challenges are *what* we do. It's the lens through which we look at everything in our school."

The school, which is both a magnet school and a lottery school required to take half of its students from families where the parents did not go to college, is designed around project-based learning and "the four Cs": communication, collaboration, creativity, and critical thinking.

The Grand Challenges are an ideal organizing principle, Parker said. "You can't go around our school without seeing the Grand Challenges. They're on the website, in student manuals, on the bulletin boards, in every classroom…. It's something that we talk about on a daily basis."

For example, students are required to do job shadowing in their sophomore year, and the jobs are chosen on the basis of the Grand Challenges. Students visit a nearby nuclear power plant to learn about energy. They work with the Department of Transportation to learn about

infrastructure. “Even when we’re doing job shadowing, we’re thinking about the Grand Challenges.”

The Grand Challenges have increasingly been embraced by teachers in non-STEM subjects, Parker reported. Administrators introduce and emphasize the Grand Challenges to incoming teachers and ask them to do a project involving one of the challenges. “If administrators say, ‘You just have to do one,’ they’ve found that people did one and got really excited about it. And then the next year, they did that one and came up with another one, and then they came up with another one—and the next thing they knew everybody was doing Grand Challenges all the time.”

For her Algebra I class, Parker described a project in which the students partnered with a local organization working with two villages in India on clean water issues. While learning about algebra, students also got to work on solutions that are critically important to the people in those villages. In another class, students did a project on nuclear terrorism where they learned about energy, proliferation, international policymaking, and science. “We don’t keep everything inside [students’] bubble.”

To fund these programs, the school often turns to businesses. “We would not be able to do our school the way we do if our business community had not embraced us,” she said. “We have a lot of business partnerships, and the more of those we can make, the better.”

Pull quote: For an Algebra I class, students partnered with a local organization working with two villages in India on clean water issues.

PREPARING TO CHANGE THE WORLD AT TESLA STEM HIGH SCHOOL

Tesla STEM High School in Redmond, Washington, also weaves the Grand Challenges throughout the school, said teacher Cynthia Burt. For example, on the first day of ninth grade English, students look at the Grand Challenges pamphlet and website and begin a creative writing project in which they speculate about what the world will be like if a Grand Challenge either has or has not been solved. The school has its students conduct research investigations, develops digital literacy in its students, and integrates science, engineering, and the humanities. “My students are forward looking,” said Burt. “They have this energy that I haven’t felt before throughout the classroom. They feel empowered to change the future.”

In their junior and senior years, students have a choice of four laboratory courses: engineering science and sustainable design, forensics and AP psychology, AP physics and global engineering, and human anatomy/physiology and biomedical engineering. They also do internships and partnerships with businesses. Students have worked with companies to develop a solar-powered mobile lighting system for remote construction projects, an electrocardiogram unit, recyclable plastic composite coffee cups, and sustainable and feasible green buildings. “We have a great panel at our school that goes out and finds businesses that will come and work with our students.”

Burt quoted from a letter she received from a former student who went to Rice University: “Blessed with a high school education driven by the Grand Challenges for Engineering, I entered college with unparalleled enthusiasm and an aspiration to change the world. Despite the constant and unexpected failures I experienced my freshman year, the Grand Challenges became a source of encouragement that drove me to ask questions, welcome failure, and persevere. Because I’m fortunate enough to have this education that holds the answers to engineering better medicines

and providing people with access to clean water, I strive to devote these resources I have to reaching out to those in need."

*Pull quote: "*My students are forward looking. They feel empowered to change the future."

SIMULATING SOCIETY AT BYRON HIGH SCHOOL

For his first few years at Byron High School in Minnesota, Andy Pethan, a recent graduate of Olin College, was a FIRST Robotics coach. "That program has been the kind of thing that you can bolt on to the side of a school and all of a sudden create a lot of energy around STEM," he said. Drawing on that experience, he set out to create the same kind of energy and enthusiasm through a new course in his traditional nonmagnet public school.

Grand Challenges Design "puts students in front of major issues like energy production, transportation, water quality, fair governance, health care, and urban infrastructure." It centers on a simulation played in the classroom on a board perched atop a 6' x 13' wooden table that the class built. The board is split in half by a river—with water in it—with 600 hexagonal plots on either side. The board includes a cup of soil in which students can grow plants.

As the game grows in population, students have to do things like build apartment complexes and residential plots to sustain more people. Industry develops to provide goods for the population, requiring transportation systems to move the goods. Pollution from residential and industrial uses is initially negligible but eventually needs to be treated.

While the simulation is played out on the physical board, a digital board tracks things like health, how much money is in the economy, and what goods are being transferred. The need to manage an economy with limited resources creates the need for governance, which entails taxes and shared infrastructure. "These are the kinds of nontechnical concerns that can enable or completely shut down a good technology solution," Pethan explained.

Students are the ones building the simulation and making decisions. To maximize health, wealth, and happiness, they need to figure out the best solutions. They receive advice from older mentors, some with industry experience.

"The Grand Challenges Design class is not just a game of creativity and diplomacy," said Pethan. "The idea is that they actually need to do all these things. It's an engineering class."

Starting next year, another teacher at the school is hoping to offer economics and government credit in some form to students for working on the simulation. "Imagine if students could get a large percentage of their required credits in the context of doing this kind of work," said Pethan.

Once some issues with the simulation are resolved, Pethan's intention is eventually to package it so that other schools can use as much of it as they want. "Everything we're building is going to be totally open source, from the game code to the rules to the process of how to get it up and running."

Pull quote (choice):

A Grand Challenges Design course "puts students in front of major issues like energy production, transportation, water quality, fair governance, health care, and urban infrastructure."

"The Grand Challenges Design class is [about] creativity and diplomacy. [And] it's an engineering class."

ATTRACTING GIRLS TO ENGINEERING THROUGH "GIRLS ENGINEERING CHANGE"

For the entrepreneurship and service components of the Grand Challenges Scholars Program at Duke University, Christine Schindler and Melina Smith developed a nonprofit organization that they have run since graduation.

Girls Engineering Change holds workshops for middle school students, hosted by college students, in which girls learn about a problem and how engineering can be used to address it. The teams build projects in two to four hours that address a particular need, such as solar-powered USB chargers, electrocardiogram simulators, and small electronic games, which are then donated to organizations that can use the devices.

"By showing girls that in two hours they're building something that we actually donate," they learn for themselves "what they could do if they devoted their lives to engineering," said Schindler. Added Smith: "With 57 percent of college students being female and only 18 percent of engineering students being female, we saw this problem firsthand and we felt compelled to do something about it."

Girls Engineering Change has reached more than 1,000 girls and has involved more than 300 university volunteers. At the same time, it continues to need partners and support to achieve its mission. "What we want to do is inspire the next generation of female engineers to make the world a better place," Schindler said.

Pull quote: "By showing girls that in two hours they're building something that [is donated for use, they learn] what they could do if they devoted their lives to engineering,"

MOTIVATING STUDENTS IN FAIRFAX COUNTY, VIRGINIA

Fairfax County Public Schools, the tenth largest school district in the country, with about 200,000 students and 200 schools, has begun offering a three-year program in which a cohort of 90 high school students learn mathematics, science, and engineering in an interdisciplinary project–based fashion, explained Scott Settar, program manager for technology and engineering education in the school system.

For example, in a three-year project on providing clean water to remote destinations, students learn about biology, physics, chemistry, algebra, geometry, precalculus, and engineering, and they have the option of a fourth year to delve deeper into specific content areas. The program also allows for work-based learning opportunities for seniors to partner with local and regional businesses and receive high school credit.

The program was created in collaboration with the Virginia Department of Education, which has an innovation grant that has enabled the district to do things differently from a traditional high school. The grant "allows us some flexibility to break down the silos and teach the content in an integrated fashion." The new program is a school within a school where students are divided into small groups to solve Grand Challenges.

The school system also is partnering with a nearby university to provide college-age mentors and prepare students for college-level work, and the National Academy of Engineering has helped create a framework and curriculum for the program in addition to providing speakers and business contacts. Businesses such as Boeing have been strong supporters of the program and have worked at middle and elementary schools to promote engineering and the Grand Challenges.

As Settar put it, content is important, skills are more important, and motivation is the most important. Thus the program "motivat[es] students as to why this content is important for them to learn and what is the potential impact they can have, not only in their communities but from a global perspective."

One challenge, Settar noted, has been working with parents to demonstrate why students who have taken this program instead of a traditional program are not disadvantaged in college admissions. The point to stress is that colleges want the skills that the program graduates have. "We hear from deans of engineering when we go out and collaborate with universities that these are the skills they want our students to have in addition to the content" knowledge, Settar said.

Pull quote: "We hear from deans of engineering that these are the skills they want our students to have in addition to the content" knowledge.

INSTITUTING THE GRAND CHALLENGES AT ALL GRADE LEVELS IN NORTH CAROLINA

The state of North Carolina is using the Grand Challenges "as a scaffold to motivate students at all ages, starting in kindergarten all the way up through graduate school," said Laura Bottomley, director of Women in Engineering and the Engineering Place at North Carolina State University. Elementary schools are using projects such as creating better medicines as an introduction to engineering. Middle and high schools are organizing classroom and afterschool activities around the Grand Challenges. Thirty-two summer camps around the state are based on the Grand Challenges. The Research Experiences for Teachers project in North Carolina is tied to the Grand Challenges, with teams of K–12 teachers, education students, engineering students, and community college teachers.

Bottomley illustrated the power of the Grand Challenges to change lives with the story of a girl named Sidney. The middle school student was initially very skeptical when she came to a summer camp on the Grand Challenges six years ago. But when Bottomley gave a presentation on reverse-engineering the brain, Sidney got interested. "Do engineers really care about music?" she asked Bottomley after the talk. "I said, 'Are you kidding? Half the band at NC State is engineers. There's definitely a link between math and music.'" After a great week, Sidney returned to the camp through high school. Today, after doing research at Johns Hopkins University as a high school student, Sidney is planning to attend NC State and

major in chemical engineering with a minor in neurobiology so she can work on reverse-engineering the brain.

"The Grand Challenges are challenges," Bottomley concluded, "but as we've seen this morning and as we'll continue to see, they're incredibly inspirational. It's an opportunity to grab kids starting in kindergarten…and motivate them to go forth and make a difference in the world."

One challenge, she noted, is generating a unified national effort to provide teachers with the professional development they need to teach engineering. The American Society of Civil Engineers (ASCE) has developed standards for teacher professional development, and about 700 members of the society's K–12 division are engaged in professional development, but more needs to be done, she said.

Pull quote: "The Grand Challenges are incredibly inspirational…and motivate kids to go forth and make a difference in the world."

4
The Grand Challenges as a New Model for Higher Education

Points Highlighted by the Speakers

- The activities with which students engage in the Grand Challenges Scholars Program are associated with later success.
- The Grand Challenges help develop mindsets that transcend individual courses.
- Additional research could further identify and characterize the skills developed by the Grand Challenges Scholars Program that foster success.
- Many fields could benefit by identifying the most pressing and important issues they confront.
- Challenges in other fields will require the contributions of engineers, just as the Grand Challenges require contributions from nonengineers.

By providing students with mentors, experiential and service learning, and a solid grounding in the global, entrepreneurial, and interdisciplinary dimensions of learning, the Grand Challenges offer the kind of education that all students should receive. "Is it any wonder that the Grand Challenges Scholars have a totally different trajectory than the vast majority of our college students?" asked the moderator of the fourth panel, Peter Kilpatrick, the Matthew H. McCloskey Dean of Engineering at the University of Notre Dame.

But providing all students with these experiences is a major design challenge in higher education, Kilpatrick continued. Faculty members and administrators need to be charged up and filled with hope, he said. They need to draw on the examples of other institutions that have organized their activities around major challenges. They need to see the big picture, not just isolated parts of the curriculum.

The Grand Challenges provide a way to achieve these ends, he said. "It's not the what, it's the why…. If you get the why right, everything else falls into place."

In the final panel of the meeting, presenters with extensive experience in higher education pointed toward possible futures for colleges and universities based on the lessons provided by the Grand Challenges Scholars Program.

Pull quote: "It's not the what, it's the why…. If you get the why right, everything else falls into place."

GRAND CHALLENGES IN OTHER FIELDS

The Grand Challenges have inspired other organizations, directly or indirectly, to identify similar sets of problems, said Thomas Katsouleas, executive vice president and provost at the University of Virginia. For example, the American Academy of Social Workers adopted its own 12

challenges, clearly inspired by the NAE Grand Challenges, involving family violence, incarceration, and social isolation, among other concerns. And through conversations with colleagues, Katsouleas found that similar grand challenges could be identified for other fields, such as access to justice or balancing justice and privacy in the law, or zero-error dosing and resilient caregivers in nursing.

Some related programs in higher education, such as the Clinton Global Initiative and the United Nations Sustainable Development Goals, cast their challenges in terms of both framing goals and motivating students. The Clinton Global Initiative, for example, pairs students with global leaders to solve particular societal problems. Other initiatives touch on entrepreneurship. These include the programs of the Lemelson Foundation, whose mission is "improving lives through invention"; Ashoka U (in partnership with the Cordes Foundation), a social entrepreneurship consortium that supports innovation awards; and the BALSA Foundation in St. Louis, whose mission is "to promote social equity and prosperity in the St. Louis region by empowering first-time entrepreneurs to start and grow their businesses."

Several initiatives offer opportunities for service and experiential learning. The sustainable cities program at the University of Oregon, for example, connects courses to community projects and sustainability. Design for America, which was founded at Northwestern University, has 36 participating universities, making it similar in size to the Grand Challenges Scholars Program. Aimed at both engineers and nonengineers, it provides formal instruction plus design-oriented community projects ranging from creating hypoallergenic teddy bears to improving the voter experience.

Global experiences are another feature of these efforts, as with challenges from the Bill & Melinda Gates Foundation and the US Agency for International Development. Such experiences can be critical to students' prospects, said Katsouleas: he reported that among students who had semester abroad experiences, 90 percent had job offers within a year of graduation, compared with less than 50 percent of graduates as a whole.

Finally, many initiatives in higher education are characterized by interdisciplinary curricula. For example, the Emerging Leaders in Science and Society (ELISS) program, sponsored by the American Association for the Advancement of Science (AAAS), recruits PhDs in science from across the country to participate in a 15-month program to develop soft skills such as leadership and apply those skills to social needs. The University of Vermont's master of science in leadership for sustainability combines environmental science and experiential learning. The Frank Batten School of Leadership and Public Policy at the University of Virginia combines public policy with applied social sciences to develop leaders.

Katsouleas drew several lessons from this brief overview. Students often request that mentoring be more structured, but the most effective mentors are those who are guides on the side. Mentoring "is an art, and it fails if it's either too close or too far," he said.

A second lesson is that many successful programs have a respected sponsor, such as the AAAS, the Clinton Foundation, or the Gates Foundation. This is the role of the NAE with the Grand Challenges for Engineering.

Finally, Katsouleas reiterated the point that many fields could benefit by identifying the most pressing and important issues they confront. But in each case, he added, these challenges will not be solved without engineering, just as the Grand Challenges for Engineering cannot be solved without the involvement of other disciplines.

Pull quote: Many fields could benefit by identifying the most pressing and important issues they confront. These challenges will not be solved without engineering, just as the Grand Challenges for Engineering cannot be solved without the involvement of other disciplines.

THE GRAND CHALLENGES AS A DRIVER OF CHANGE IN HIGHER EDUCATION

The Grand Challenges Scholars Program has become a poster child for change on a broader scale in higher education, said Richard Miller, president of Olin College of Engineering and a cofounder of the Grand Challenges Scholars Program.

Ultimately, the Grand Challenges are about the continuation and enhancement of human life on the planet, said Miller. Since 1920, the Earth's population has grown from 2 billion to 7 billion and is on its way to more than 9 billion. When population biologists see graphs showing such a population increase, they typically expect a crash to follow, said Miller. "You can make the case that the survival of the human race depends on thinking differently *now*."

This new way of thinking will depend on much more than knowledge and skills, Miller continued. He paraphrased a popular inspirational poster: "More often than not, your attitude, not your aptitude, determines your altitude in life." Higher education focuses relentlessly on aptitude, but success is more about "attitudes, behaviors, and motivations." In particular, he cited seven markers of success, drawn from a variety of sources:

- Entrepreneurial mindset
- Ethical behavior
- Teamwork, leadership
- Global perspective
- Interdisciplinary thinking
- Creativity and design
- Empathy, social responsibility
- Employability skills.

Together, he said, these attributes can be represented as mindsets. "This is about something that transcends courses," he observed. "It's a way of thinking." But he clarified that the mindsets can be defined, measured, and taught. Carol Dweck at Stanford, who has written a book on the subject, has shown that children who have a "growth mindset" tend to progress academically, as measured by their mathematics grades, while those with a fixed mindset tend to decline.[5] "What children believe about why they succeed is more powerful than what you teach them," said Miller. At the University of Pennsylvania, Angela Duckworth has done similar work on what she terms "grit."[6] Norman Augustine, former chairman and chief executive officer of Lockheed Martin Corporation and the author of a

[5] Dweck, Carol. 2006. *Mindset: The New Psychology of Success*. New York: Random House.
[6] Duckworth, Angela. 2016. *Grit: The Power of Passion and Persistence*. New York: Scribner.

book of observations drawn from his life, recently coined a new law that "motivation almost always beats raw talent."[7]

On a personal note, Miller recounted the story of his freshman advisor at the University of California, Davis, Mel Ramey, who was being honored the week after the meeting for his service to students and the university. As one testimonial to Ramey put it, "Hopeful faculty members spread hope among their students, while cynical faculty members spread cynicism." As Miller put it, "Have you ever met a cynical entrepreneur? You haven't, because it's an oxymoron." By the same token, faculty members who spread hope are spreading a mindset, "and it's time that we owned that and said that this is what happens when we teach. This profession is about shaping lives. And that realization is powerful."

In 2014 the Gallup Company, in partnership with Purdue University, released the results of the largest survey of college alumni ever conducted. It found that emotional support, as embodied in mentors and deep experiential learning, doubled alumni's chances of success in life, as measured by their social, financial, community, and physical well-being. Miller has made the same observations at Olin College of Engineering.

By the time Olin students graduate, they will have completed 20 to 25 projects and started a business. They have not just knowledge and skill but "a really good head start on developing a purpose or a mission or a calling in life," he said. "How much is that worth to you? I can tell you, from the letters that I get from parents, that it is worth more than the starting salary, particularly for kids who weren't necessarily grounded when they came as freshmen [or who were] emotionally shy. [When they get their diploma on graduation day] they walk across the stage a lion, ready to take on the world."

The problem, Miller continued, is that only about 3 percent of college students receive the positive elements that correlate with greater preparedness in life, including good mentoring and deep experiential learning. But, he said, "I believe that 100 percent of the Grand Challenges Scholars have had both. And that's why I think this program is going to transform education."

Olin has worked with its neighboring institutions of Wellesley College and Babson College, neither of which has an engineering program, to structure its engineering program around design thinking. "Essentially every student in all eight semesters has a design focus for at least one of their classes, and design welcomes people from other disciplines to join." Design thinking is different from project-based learning. "It is like learning to paint from a blank sheet of paper. You first decide what to paint, what it should look like in terms of size and shape. If you do that, kids from archaeology, from anthropology, from business all have an equal footing, and this gets them very excited about learning quantitative material."

Pull quote: Olin College's intercollegiate design course welcomes students from other disciplines—"archaeology, anthropology, business—all have an equal footing, and this gets them very excited about learning quantitative material."

CREATING A THIRD SPACE FOR EDUCATION

Ernie Wilson, Annenberg Chair and dean of the Annenberg School for Communication and Journalism at USC, agreed that mindsets are critically important and has been exploring the

[7] Augustine, Norman. 1997. *Augustine's Laws*, 6th ed. Reston, VA: American Institute of Aeronautics and Astronautics.

hypothesis that they tend to differ between people with a traditional business education, those with a communications education, and those trained as engineers.

In a study of 900 executives on Wall Street, 92 percent said that soft skills are equally important or more important than technical skills. Furthermore, the absence of soft skills is expensive for the American economy. Wilson cited a study by McKinsey and Company of four sectors of the US economy, showing that companies in those sectors are leaving between $800 billion and $1 trillion a year on the table because their employees lack interactive skills. “This is real money, and it’s real money today and not in the future.”

Soft skills are being undersupplied by higher education. Over the past several years, Wilson has talked with 75 to 100 executives across multiple sectors of the US economy to ask, “What can we do better?” Based on their answers, he has developed what he calls the Third Space in education, beyond the first space of engineering education and the second space of business education.

The Third Space is “a distinctive way of thinking about problems, identifying opportunities, and avoiding risks,” with five dimensions: intellectual curiosity, empathy, 360-degree thinking, adaptability, and cultural competency. These are the skills executives want, Wilson stated, and they want them quickly, through executive education programs as well as undergraduate and graduate programs.

These attributes can be measured, identified, quantified, and assessed on an individual level. Most importantly, said Wilson, they can be integrated into a portfolio that enables individuals to think differently, to have a different mindset, to employ a different mental model. He acknowledged that few people will excel in all five attributes, but “if you, as a leader, don’t have an appreciation of all five…and know how to build teams that have all of those attributes, you’re unlikely to be successful.”

During the past few years, Wilson has been working with faculty members at USC to expose about 300 undergraduates to the five skills across a number of classes. Faculty members also have done executive education, and speakers from business have come to the university to talk with students and faculty.

More research needs to be done on defining and understanding soft skills, he said. “Is there a hierarchy of soft skills? My hunch is that empathy and intellectual curiosity provide the foundational base and that cultural competencies and adaptability are more easily transferred or learned.”

The prospects for developing and adapting these skills are so enticing that Wilson is stepping down from his job as dean to work full time on Third Space skills. He has met with senior officials in China who are equally interested in these skills, particularly in the context of the challenges facing China in areas such as pollution and economic development. “If Silicon Valley—the uber-capitalists—and the Communist Chinese are saying the same thing, then there’s probably something there.”

Pull quote: Intellectual curiosity, empathy, 360-degree thinking, adaptability, and cultural competency are the skills executives want, and they want them quickly.

TELLING THE STORY OF ENGINEERING

Lockheed Martin has about 50,000 engineers and hires thousands of engineers each year, so "engineering education is an existential topic for us," said Jeff Wilcox, vice president for engineering for Lockheed Martin, which has been the lead sponsor for all three of the Global Grand Challenges Summits.[8]

Many of the company's engineers are on the verge of retirement, so the hiring of new engineers is critical. Yet academia and industry have an "impedance mismatch," said Wilcox. Furthermore, the work of engineers continues to be hampered by a lack of understanding of what engineers do.

Former NAE President "Chuck Vest used to say that the E in STEM is silent," said Wilcox. "We don't do a good job of telling our story. We need to learn to tell our story, but we also need to learn to partner with those who are professional story tellers. Engineering to me is a verb. This is not just about engineers by degree. It's about those who create."

The Grand Challenges can serve as a unifying framework both in engineering education and in public understanding of engineering. They allow different generations of engineers to "have the same conversation in an integrated fashion," said Wilcox. Such conversations make it possible to "pass the baton" from older engineers to newer ones, "again organized around this wonderful construct of the Grand Challenges."

Wilcox closed with a quotation from Winston Churchill: "Engines were made for men, not men for engines. Expert knowledge, however indispensable, is no substitute for a generous and comprehending outlook upon the human story with all its sadness and with all its unquenchable hope."[9]

Hope, said Wilcox, is the animating force behind the Grand Challenges and the Grand Challenges Scholars Program.

Pull quote: "We need to learn to tell our story…. [It's] not just about engineers by degree. It's about those who create."

DEVELOPING HIGHER-ORDER INTELLECTUAL SKILLS

Moderator Kilpatrick reiterated some of the speakers' points in his brief remarks during the panel. He noted that the Grand Challenges Scholars Program develops habits of mind that push students in the direction of higher-order forms of intellection such as the following[10]:

- extension
- completion
- testable hypotheses
- ideation
- synthesis

[8] The first two summits, cohosted by the Chinese Academy of Engineering, UK Royal Academy of Engineering, and US National Academy of Engineering, were held in Beijing in 2013 and London in 2015; the third will take place July 18–20, 2017, in Washington, DC. Information about the summits is available at the Grand Challenges website (www.grandchallenges.org).

[9] Remarks at the University of Miami, February 26, 1946.

[10] This list was articulated by Daniel Little in *Varieties of Social Explanation: An Introduction to the Philosophy of Social Science* (1991; Boulder: Westview Press).

- transference
- translation
- application
- paradigm shifts.

The program, he said, “opens up students’ minds to be adaptable, to be sufficiently culturally competent, to be intellectually curious, to be holistic thinkers.”

It is also markedly international. It has generated interest among engineering deans the world, and international conferences on engineering education have focused on the Grand Challenges.

The Grand Challenges give people a vision, Kilpatrick said, “and there’s nothing more powerful than a vision to move people to action.”

Pull quote: The Grand Challenges give people a vision, “and there’s nothing more powerful than a vision to move people to action.”

5
Grand Challenges at the Office of Science and Technology Policy

Points Highlighted by the Speakers

- The Grand Challenges have many parallels with initiatives undertaken by the Obama administration.
- The Computer Science for All initiative aims to increase diversity in the professions that use computer science by making CS education available to all American students.
- The National Nanotechnology Initiative and the Materials Genome Initiative have linkages with Grand Challenges such as reverse-engineering the brain.
- Like the Grand Challenges, the Makers Movement is inherently interdisciplinary and solutions oriented.
- Initiatives in the areas of organ transplants, smart cities, and active learning all relate to critical aspects of the Grand Challenges.

Engineers have been "great partners for President Obama on a broad range of science, technology, and innovation issues," said Tom Kalil, deputy director for technology and innovation at the Office of Science and Technology Policy (OSTP). Such issues include advanced manufacturing, cybersecurity, neuroscience, synthetic biology, the future of computing, and increasing the number of STEM graduates.

"Whether it's accelerating the transition of the world economy, or making sure that everyone has safe drinking water, or allowing Americans to live longer and healthier lives, or dealing with emerging threats in homeland security, engineers play a major role," he said. "To the extent that we can get young people exposed to these problems as undergraduates, [they] can have an important impact on the trajectories" of potential solutions to issues of national and international importance.

Kalil also made the case that the Grand Challenges Scholars Program can inform the intellectual agenda of America's research universities. Through its emphasis on hands-on projects or research experience, interdisciplinary curricula, entrepreneurship, global dimensions, and service learning, the program can influence priorities for faculty recruitment, capital campaigns, and external partnerships.

UCLA, for example, has selected two major Grand Challenges for its program: dramatically improving the ability to diagnose and treat depression, and making the Los Angeles region 100 percent sustainable in energy and water use by the year 2050. UCLA aims to make the biggest possible impact by taking a holistic approach that encourages faculty, students, and supporters from all disciplines to work together on common issues.

And Indiana University has started a process, led by Anantha Shekhar, the institution's assistant vice president for clinical affairs and executive associate dean for research at the IU School of Medicine, to identify precision health as a universitywide Grand Challenge.

Kalil raised several practical questions associated with the Grand Challenges approach:

- What are the pedagogical implications of aiming to inspire and empower young people to tackle big problems?
- How can colleges and universities interact with K–12 institutions to introduce students to the Grand Challenges much earlier in their education?
- How can universities and the federal government work together most effectively to solve the Grand Challenges?

Important steps have been taken regarding all three of these questions, he said, but much more needs to be learned and done.

During the meeting's afternoon session, in the Old Executive Office Building next to the White House, Kalil and other OSTP staff members described the overlap between several White House initiatives and the Grand Challenges for Engineering. They also participated in breakout session discussions on expanding and refining the program (see chapter 6).

Pull quote (choice):

"Whether it's accelerating the transition of the world economy, making sure that everyone has safe drinking water, allowing Americans to live longer and healthier lives, or dealing with emerging threats in homeland security, engineers play a major role."

"To the extent that we can get young people exposed to these problems as undergraduates, [they] can have an important impact on the trajectories" of potential solutions to issues of national and international importance.

COMPUTER SCIENCE FOR ALL

Ruthe Farmer, senior policy advisor for tech inclusion at OSTP and former chief growth and strategy officer at the National Center for Women and Information Technology, has been working on the Computer Science for All Initiative, which aims to make CS education available to all American students by training teachers, expanding access to high-quality instructional materials, and building effective regional partnerships. The initiative has designated $4 billion through the Department of Education for computer science education at the K–12 level, with additional commitments from some of the nation's largest philanthropists and technology companies.

Only about a quarter of schools in the United States offer a computer science pathway with programming and coding, and minorities and women are vastly underrepresented in the field. "We are underutilizing a tremendous amount of talent," Farmer said.

The Computer Science for All Initiative has sparked dramatic growth and excitement in the computer science community. For example, more than 80 universities have pledged to support it as well as computer science and education departments in universities to train existing and future CS teachers. "We need to build those pathways," Farmer said.

Pull quote: Minorities and women are vastly underrepresented in computer science. "We are underutilizing a tremendous amount of talent."

MATERIALS BY DESIGN AND THE MATERIALS GENOME

Lloyd Whitman, assistant director for nanotechnology and advanced materials, has been leading the National Nanotechnology Initiative and the Materials Genome Initiative, launched by President Obama in March 2011.

The Materials Genome Initiative aims to help businesses discover, develop, and deploy new materials to stay competitive in today's global economy. The National Nanotechnology Initiative—which is also tied to the White House BRAIN Initiative—is a research and development effort with 20 departments and independent agencies working together to better understand and control matter at the nanoscale level.

Computers work basically the same way they have worked for decades, observed Whitman. They are superb with tasks like numerical computations but are still rudimentary at tasks such as human perception. The Grand Challenge is to create a new type of computer that can collectively interpret and learn from data, solve unfamiliar problems using what it has learned, and operate with the energy efficiency of the human brain.

This challenge has been particularly effective in getting computer scientists and neuroscientists to talk and work with each other, said Whitman. "It's a great challenge to break down silos and get people from wholly different faculties thinking about what it will take to do this."

Pull quote: The Grand Challenge is to create a new type of computer that can collectively interpret and learn from data, solve unfamiliar problems using what it has learned, and operate with the energy efficiency of the human brain.

THE MAKER MOVEMENT

Andrew Coy, OSTP senior advisor for making, reported that universities have started to embrace the Maker Movement. Like the Grand Challenges, the movement is inherently interdisciplinary, breaking down the barriers between disciplines that characterize most schools.

He described a strictly disciplinary approach as "the equivalent of eating bread by eating a cup of flour, taking a drink of water, having a teaspoon of yeast, and then lying around and saying that's bread, which is disgusting. That's not bread. It's only the ingredients of bread, and relying on someone else to mix them is a poor use of the resources that we have."

The president's Nation of Makers Initiative, a nonprofit effort with public and private sector support, is designed to empower students and adults to make their ideas into reality. It will support spaces, events, and organizations, all with the interdisciplinary character of the Grand Challenges. Over time, it will build making into the educational pipeline to create the next generation of problem solvers and innovators.

The initiative "brings people in to understand why [making] matters and how they can get involved," said Coy. "It's a great point of leverage to make other universities' success your own."

Pull quote: Like the Grand Challenges, the Maker Movement is inherently interdisciplinary, breaking down the barriers between disciplines that characterize most schools.

ORGAN TRANSPLANTS

Jennifer Erickson, assistant director for innovation for growth, has been working on reducing and eventually eliminating waiting lists for organ transplants. As she pointed out, dialysis has saved millions of lives, but the basic technology was invented 70 years ago.

"The vast majority of people who are waiting for an organ are waiting for a kidney," she said. "It's a personal tragedy for them and their families. It's also a major issue for taxpayers, because the only disease that automatically qualifies you for Medicare is kidney failure. We spend $34 billion each year on this 70-year-old technology. That's a lot more than we spend on space exploration. It's more than we spend on the Marine Corps. This is where we want your help."

President Obama issued a call to action to reduce and ultimately eliminate the waiting list for organ transplants. Every day, 22 Americans die waiting for a transplant. It will take a team of people to solve this problem, Erickson said. Maybe the answer will be some sort of device that people wear on a belt. "There are a lot of different technologies [emerging], I'm sure many in your labs."

Dramatic advances are also needed for many other organ systems. For example, transportation and refrigeration advances would greatly reduce the number of people waiting for heart and lung transplants. Currently, most organs can be stored for only a few hours, so viable transplants are often discarded. "This is something that your students can crack, and they can crack it quickly. And what's so exciting about this is it will touch people's lives immediately and save lives and money at the same time."

Pull quote: Transportation and refrigeration advances would greatly reduce the number of people waiting for organ transplants. "This is something that students can crack…. it will touch people's lives immediately and save lives and money."

SMART CITIES

Daniel Correa, senior advisor for innovation policy, has been leading a "smart cities" effort designed to work with communities through a place-based approach on the major challenges facing society.

He cited the MetroLab Network, in which universities and cities are working together using modern data tools to measure success, monitor progress, and scale up successful community-based innovations. The collaborations take advantage of the growing data revolution, low-cost sensors, and research partnerships to uncover effective measures in alleviating community problems.

For example, a project on smart traffic lights in Pittsburgh could reduce congestion by 40 percent. The city of Louisville is using data from sensor-equipped asthma inhalers to

understand the connection between asthma "hotspots" and environmental factors and develop effective policies.

"It's research that also has a public benefit," Correa said. In addition, it brings together students in undergraduate and graduate programs to tackle common challenges at the local level. "There is a real dedication and opportunity here."

Pull quote: Undergraduate and graduate students work together to tackle common challenges at the local level, doing "research that has a public benefit."

ACTIVE LEARNING

Finally, Kumar Garg, assistant director for learning and innovation, pointed to the parallels between the Grand Challenges and the administration's efforts to promote active learning.

Research has shown that experiential and hands-on learning are the most effective ways to learn, Garg observed, and they are especially attractive to women and other groups that have been underrepresented in engineering. Yet many faculty members continue to teach exclusively through lecturing. "We have a huge culture gap in this area."

The National Science Foundation and other federal agencies have been making grants to both study and expand active learning at all levels of education. The administration also has sponsored an "active learning day" for faculty members to talk about the active learning measures they are using in their classrooms.

"We want to celebrate this, so that if it's not on the radar it will be. It's a relatively simple pedagogical fix that can get students way more engaged."

Pull quote: Research has shown that experiential and hands-on learning are the most effective ways to learn. "It's a relatively simple pedagogical fix that can get students way more engaged."

6
Suggestions from Breakout Groups

During the afternoon session, meeting participants divided into three subgroups to talk about the future of the Grand Challenges Scholars Program. In the final plenary session afterward, representatives of each group summarized the observations and suggestions made during the breakout session.

The following ideas for expanding and strengthening the Grand Challenges Scholars Program are drawn from the notes and presentations of the subgroup representatives. Both as specific suggestions and as spurs for further thought and discussion, they point in promising directions for the future of the program. They should not be seen as the consensus conclusions of the subgroups as a whole or of the National Academy of Engineering, nor are they an exhaustive list of possible steps forward.

IDENTIFYING BEST PRACTICES AND DEVELOPING RESOURCES

- Reorient existing institutional resources toward the Grand Challenges Scholars Program even as additional internal and external resources are sought.
- Provide low-, medium-, and high-intensity ways for students to satisfy the components of the program.
- Seek to involve non-STEM disciplines and faculty members in the program.
- Have deans of different disciplines coteach Grand Challenges and interdisciplinary courses.
- Reward structural alignment when Grand Challenges initiatives are universitywide.
- Share ideas on partnering with schools, other colleges and universities, and other potential partners.
- Provide opportunities, resources, and advice for students to prompt reflection on activities associated with the Grand Challenges, thus enabling them to form connections with other activities in which they are engaged.
- Build a sense of community among students and educators.
- Provide mentoring of Grand Challenges Scholars by industry representatives, faculty members, older students, program alumni, and others.
- Create a formal program to train student and faculty mentors.
- Provide guidance to parents on the Grand Challenges Scholars Program.
- Have students share their portfolios electronically, both within and across institutions.
- Hold an annual symposium or student panel organized around the program.
- Track the success of early Grand Challenges Scholars.

CREATING LINKS TO K–12 PROGRAMS AND BUILDING NETWORKS

- Develop tiered programs to more directly link elementary schools to middle schools to high schools to colleges and universities, to produce continuity in educational programs based on the Grand Challenges.
- Use Parent Teacher Associations to introduce and integrate the Grand Challenges into the educational system.
- Integrate the Grand Challenges into existing collaborations between universities and school districts, such as the UTeach programs.
- Incorporate the Grand Challenges into colleges of education and elsewhere in universities that deliver preservice education.
- Partner with campus community engagement offices to identify service opportunities.
- Explore the potential for research grant supplements to support Grand Challenges Scholars.
- Form networks to connect students with other students, faculty members, partners outside higher education, program alumni, and others.
- Create regional networks of institutions and ways for colleges and universities to share best practices by institutional size to address the challenges of small or geographically isolated institutions.
- Create a national organization of Grand Challenges Scholars as a way to connect students across the country.
- Create an international network for the program and study opportunities to cooperate internationally.

EXPANDING THE MOVEMENT, RAISING VISIBILITY, AND BUILDING SPONSORSHIP

- Develop a national communications plan, relying on both traditional and new media, to inform people who influence parents, high school students, faculty members, and potential sponsors.
- Use student testimonials, social media, and other forms of communication to advocate for and promote the program.
- Capture students' voices to motivate expansion of the program.
- Create a Facebook group for Grand Challenges Scholars.
- Engage corporations, foundations, wealthy individuals, and other potential sources of support.
- Create a Grand Challenges Scholars Program advisory board of external supporters of the program.
- Use teams of interested faculty members and students to build new and existing programs.
- Use the mandate for broader impact of research grants made by the National Science Foundation to catalyze collaborations and partnerships around the Grand Challenges.