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Views & Comments

The Power of an Idea: The International Impacts of the Grand Challenges for Engineering

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Since the dawn of civilization, advances in the fields of engineering, science, and technology have played an indispensable role in shaping humans' social and economic development. Now people face a host of global challenges that must be addressed through long-term and innovative education, research, and engineering solutions. Recognizing the growing importance of these problems, a select group of experts in 2008 identified the Grand Challenges for Engineering. The idea of naming the specific problems to be addressed for global benefit caught on immediately and has been picking up speed ever since. Among other initiatives, two very successful Global Grand Challenges Summits have been jointly convened by the US National Academy of Engineering (NAE), UK Royal Academy of Engineering (RAE), and Chinese Academy of Engineering (CAE). Rarely has an idea captured the imagination of a profession, policymakers, and the general public as rapidly and forcefully as the Grand Challenges for Engineering.

1. Major challenges confronting the world

Since the beginning of the 21st century, the world has become a multipolar system characterized by increasing economic globalization, cultural diversification, and global communications, which have reduced distances and barriers between nations and people. Accompanying these changes are significant challenges to the survival and continued development of the world as we know it.

Sustainable growth is essential to modernization. Since the Industrial Revolution, the booming development of science and technology has significantly enhanced people's material goods, wealth, and standards of living. But the world's ever-growing population is consuming the Earth's resources at a pace that cannot be sustained if humanity is to survive. For example, the rapid exploitation and consumption of traditional energy sources such as coal, oil, and gas have undermined global energy security. And the conventional development model, characterized by widespread mass production, consumption, and waste, has led to severe environmental problems and climate changes.

All people want a healthy life and basic standard of living. At the United Nations Sustainable Development Summit 2015, it was pointed out more than 800 million people are still living on less than $1.25 USD a day, and we also need to make efforts to feed the current 800 million population and the additional 2 billion population expected by 2050.

Globalization has made it easier for people to cross borders and travel great distances. But this has given rise to and exacerbated a host of public health challenges, dramatically changing the global disease spectrum. Influenza, malaria, AIDS, SARS, and other varieties of new and old infectious diseases, like the current Zika virus, pose significant threats to human health. Antibiotic tolerance and other emerging public health challenges mount in a seemingly relentless tide of epidemics and public health crises. Clear commitment and ongoing efforts are needed to counter these dangers.

Urban renovation and reinvention pose complex challenges for engineers in the 21st century. The rapid expansion of cities—in terms of geographic area, population, industrial capacity, and transportation systems—has given rise to a host of "urban diseases" such as traffic congestion, environmental deterioration, housing shortages, unemployment, severely strained infrastructure, and degrading quality of life.

Systemic risks and globalized hazards in nontraditional security fields faced by policymakers are becoming more intense, diverse, and intricate. Terrorism, economic and financial instability, evolving cybersecurity challenges, and extreme weather events all pose transnational threats.

2. The idea of the Grand Challenges for Engineering

Identified in 2008 by a committee of 18 distinguished engineers, scientists, entrepreneurs, and visionaries, the Grand Challenges present 14 goals to ensure that human life as we know it can continue on this planet. Substantial effort went into selecting the Grand Challenges. The committee received the counsel of thousands from around the world, and more than 50 subject matter experts reviewed its report. Yet the challenges can be stated simply:

- Make solar energy economical.
- Provide energy from fusion.
- Develop carbon sequestration.
- Manage the nitrogen cycle.
- Provide access to clean water.
- Improve urban infrastructure.
- Advance health informatics.

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- Engineer better medicines.
- Reverse-engineer the brain.
- Prevent nuclear terror.
- Secure cyberspace.
- Enhance virtual reality.
- Advance personalized learning.
- Engineer the tools of scientific discovery.

The premise of the Grand Challenges is straightforward but essential: How can a high quality of life and security be maintained and extended worldwide in the 21st century? This is not a national idea, a business idea, or a government idea. It is an idea that encompasses everyone on the planet.

When proposed, the Grand Challenges were not ranked in importance or likelihood of finding a solution, nor was any implementation plan proposed for solving them. Rather, they were set forth as a way to inspire the engineering profession, young people, and the public at large to seek solutions. The Grand Challenges are a call to action, and they have created a growing, global, grass-roots movement that is changing how people think about the future and about the responsibility of engineering in creating that future.

The Grand Challenges have drawn attention to the need to promote the engineering that will achieve their solution. What the public knows and learns about engineering from the media is often wrong by omission or misrepresentation. For example, the construction of the Large Hadron Collider near Geneva, which explores the fundamental constituents of nature and discovered the "God particle" (the Higgs boson), was one of the great engineering feats of modern times. Yet publicity about the collider has essentially been silent about the engineering that created it.

The Grand Challenges also have called attention to the need to stop using the word "technology" when "engineering" is meant. Technology is an outcome; it is not engineering. If the public hears nothing about engineering, how can people develop a correct understanding about engineering and what engineers do?

Solving the Grand Challenges will require contributions from many professions in addition to engineering because the Grand Challenges are engineering *system* problems. Public policy, law, medicine, international relations, and science (including the social sciences and culture) and all of humanity must be engaged if solutions to these challenges are to be created and implemented. But engineering will play a leading role in their solutions.

3. The Global Grand Challenges Summits

The most visible indicators of the global nature of the Grand Challenges have been two major international summits, with planning for a third under way, to identify opportunities for global cooperation on engineering innovation and education. Jointly sponsored by the Chinese Academy of Engineering (CAE), UK Royal Academy of Engineering (RAE), and US National Academy of Engineering (NAE), the first Global Grand Challenges Summit was held in London in 2013, the second in Beijing in 2015, and a third will take place in Washington, DC in 2017.

The Beijing summit brought together more than 800 participants from around the world, including prominent engineers, entrepreneurs, and societal leaders. Webcast globally, it also served as an online classroom for hundreds of students who attended virtually. Designed to accelerate global engagement on the Grand Challenges, the summit led to international collaborations, friendships, and a renewed sense of what engineering does for people and society.

The Global Grand Challenges Summits have several potential outcomes. They inspire more students into engineering careers. They remind both students and experienced practicing engineers of the excitement, impacts, and importance of their profession and of their responsibility to the planet and generations to come. And they communicate to policymakers and the public that a prosperous, sustainable, and secure future for the planet depends on engineers and their collaborative efforts all over the world.

Given all these possible outcomes, the most effective approach to the summits has been to select talented engineers from all over the world who are doing exciting work that could have a profound impact on the planet's future and let them tell their stories. At the summit in Beijing, speakers discussed sustainability, urban infrastructure, health, energy, education, security, and resilience, as well as a topic that seems distant from engineering but is actually central to many engineering endeavors: the joy of living. As Robert Socolow, professor emeritus of mechanical and aerospace engineering at Princeton University, remarked, "Electronics delivers us music with marvelous fidelity. Air travel brings us access to the extraordinary variety of human cultures and natural settings. Electronics nurtures our curiosity by providing incredible access to information. Engineering in its many forms enables discoveries about our universe and the history of life, which we then share." It also creates our future.

Several essential messages emerged from these stories. The first is that many of the most exciting and potentially game-changing innovations develop across the boundaries of traditional disciplines. At the Beijing summit, Guang-Zhong Yang, director of the Hamlyn Centre at Imperial College, described wearable devices and smart implants that may lead to broadly accessible and personalized health care, thus exploiting informatics for public health needs. Jack Cohen, at the University of Warwick, outlined the potential use of virtual reality to prepare individuals to engage with the various systems in our societies.

The second message is that bringing together practitioners in engineering, the social sciences, and the arts to build excellent teams, make breakthroughs, and tackle global issues, such as sustainable energy and climate change, is a mandatory step, not merely a gesture toward inclusivity.

The third message was best expressed by Microsoft founder Bill Gates during his keynote address at the first summit, in London in 2013. "The market is a tremendously powerful driver of innovation," he said, "but it has its blind spots." He pointed out that more research money was being spent on a cure for male pattern baldness than on a cure for malaria. In cases of market failure, challenge-based approaches, whether they come from government, foundations, or communities, are critical to effecting change.

The summits have produced dialogue, debate, and collaboration among their participants, from students to academy members to industry leaders to policymakers. The international gatherings have demonstrated that an international community of engineers who take cross-disciplinary, challenge-based approaches to their practice may change the world. Initiatives are already emerging that capitalize on the energy and commitment of the gatherings, such as the joint call between the research councils of the United States and the United Kingdom to pursue the challenge of clean water for all[†].

The UK Engineering and Physical Sciences Research Council, which was a partner in delivering the London summit, followed up in 2014 with its own major Engineering Grand Challenges research call. In 2016, inspired by the Grand Challenges agenda, the

[†] The collaboration was announced by the US National Science Foundation Directorate for Engineering on April 3, 2013. Available from: www.nsf.gov/pubs/2013/nsf13082/nsf13082.jsp.

UK government announced the creation of a Global Challenges Research Fund, worth £1.5 billion over 5 years, dedicated to supporting research that addresses the grand challenges that underpin global development.

4. The educational imperative

Another and even more consequential measure of the Grand Challenges' power as an idea has been their effect on education.

Preceding the Beijing summit was a Student Day that involved a business plan competition among teams of undergraduate students (six per team). The goal was to have 30 students representing each of the three sponsoring nations for a total of 90 students at the summit. Team members designated a leader (who was required to be an engineering student), and proposed and developed business plans for startup companies based on concepts related to the Grand Challenges. (Some had even developed products and applied for patents.) Each team's business plan was developed before the summit, with a final competition on Student Day judged by an international panel of entrepreneurs and innovators.

Also at the Beijing summit, the three academies and FIRST Robotics (FIRST stands for "For Inspiration and Recognition of Science and Technology") announced a collaboration that will begin at the Third Global Grand Challenges Summit in 2017. FIRST Robotics reaches hundreds of thousands of 6- to 18-year-old students through its nearly 50 000 competitions in 83 countries. In this new collaboration, the competition goals will be based on the Grand Challenges. In addition, the university Student Day competition that preceded the first two summits will continue, providing further outreach for the Grand Challenges to students, parents, sponsors, governments, corporations, mentors, and the public.

Beyond individual events, the Grand Challenges are proving to be a catalytic force in education more generally. Academic programs organized around the Grand Challenges are helping to change the nature of engineering education from a competitive, lecture-based course of study to a hands-on, collaborative, multidisciplinary, problem-solving endeavor. As an example of this approach, the curricular and extracurricular Grand Challenge Scholars Program has been established by the US NAE to prepare students to solve the Grand Challenges and problems like them. To date, more than 160 Grand Challenge Scholars have earned their degrees. The Grand Challenges movement has had an impact on the UK higher education sector as well, with many leading engineering departments now offering challenge-based courses and curricula.

Similarly, the Vest Scholarships, named for Charles Vest, former NAE president and a driving force behind the summits, pair talented students outside the United States with leading US engineering institutions. They provide opportunities for graduate students at selected international universities to pursue research addressing a global Grand Challenge at a leading US university, with expenses paid for a year of travel and study.

In 2015, in a letter of commitment presented to President Barack Obama at the White House Science Fair, more than 120 US engineering school deans announced plans to educate a new generation of engineers expressly prepared to tackle some of the most pressing issues of the 21st century, including the Grand Challenges. Each of the signing schools has pledged to graduate between 20 and 150 Grand Challenge Engineers per year who have been specially prepared to lead the way in solving such large-scale engineering system problems, with the goal of formally recognizing more than 20 000 of them over the next decade. At each institution Grand Challenge Engineers will be trained through special programs that integrate five educational elements: ① a hands-on research or design project connected to the Grand Challenges; ② real-world, interdisciplinary experiential learning with clients and mentors; ③ entrepreneurship and innovation experiences; ④ global and cross-cultural perspectives; and ⑤ social consciousness through service learning.

This approach to engineering education is especially effective in attracting and retaining women and minorities underrepresented in the field. Half of the Grand Challenge Scholars who have earned their degrees are women—compared with just 19 percent of other undergraduate engineering degrees in the United States. Women and underrepresented minorities say they are especially attracted by the idea of both doing something for people and having the potential to change the world. As one Grand Challenge Scholar put it, the Grand Challenges are about "the pursuit of something that will last beyond our lifetimes and trickle down in the history lessons taught to future generations. The Grand Challenges aren't just a call to those already in the field.… They're a call to anyone passionate about…innovation."

The Grand Challenges are also becoming a motivating force at the precollege level. A new high school in North Carolina, for example, has organized its curriculum around the Grand Challenges, and other schools are cropping up around the world. In its first year, the North Carolina school identified 5 of the 14 Grand Challenges as its connective curricular tissue. As one student said, "I never thought that an engineer could design stuff that could help in so many areas."

5. Rising to the challenges

Adoption of the Grand Challenges is more akin to a movement than a project. People in movements are drawn to needs and ideas that they adopt, nurture, and introduce to others. If an idea is sufficiently compelling, others adopt it too, thereby growing the movement. As the Grand Challenges movement grows, everyone will benefit.

Engineering has solved problems of a magnitude comparable to those of the Grand Challenges before. It has linked the world's inhabitants through innovations in transportation and communication unimaginable in previous generations. It has brought improved health and security and created devices and systems that feed more than 7 billion people. And it is constantly evolving to address current and future challenges.

Looking to the future, a coherent, coordinated, and effective response to the Grand Challenges will move humanity toward improved and sustained quality of life on this planet. It will also foster an unprecedented level of cooperation among the world's scientists and engineers. This in turn will spur further integration of economies, technologies, and societies to forge a new type of industry that boasts high-level technological content, strong economic returns, lower resource consumption, and less pollution while maximizing the advantages of current and future engineering talent.

The goal is to work toward a world where humanity and nature live in harmony, with green technology, low-carbon emissions, biological diversity, and ecological balance. Such a world will feature cleaner versions of traditional energy sources; new and renewable energy sources such as wind, solar, and nuclear power; and a diversified, optimized, clean, safe, efficient, and sustainable energy system that meets energy needs and reduces manmade contributions to climate change. Advances and refinements in medicine will create a global model of integrated health care, preventive medical solutions, and individualized medicine, building on and strengthening the intersection of multidisciplinary medical sciences and technical studies. Highly efficient and environment-friendly infrastructures will disseminate resourc-

es as well as innovative improvements. Public health and well-being will benefit from more effective risk prevention, coordinated real-time response, and post-event recovery. Enhanced systemic technical solutions will counter globalized security threats.

Such a world will be the result of successful efforts to address the Grand Challenges for Engineering. Talented and well-prepared engineers and other professionals are the key to realizing this future. We hope that more and more people, especially the young, will discover and join the global Grand Challenges "movement" as a worthy cause to which they can devote their efforts in seeking creative solutions through global cooperation.

In closing we quote SONG Jian, honorary chair of the CAE Presidium, at the first Global Grand Challenges Summit in London: "Science carries forward the unquenchable curiosity of our ancestors to understand the numerous mysteries of this world, while engineering carries forward the honed survival skills of our ancestors. This is a once-in-a-lifetime opportunity for all engineers who can bring into play their expertise and give us glimpses of how humanity will continue to persevere on this planet in order to inspire future generations."