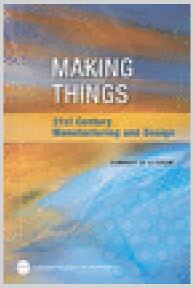


# Making Things: 21st Century Manufacturing and Design: Summary of a Forum

ISBN
978-0-309-22559-5

44 pages
6 x 9
PAPERBACK (2012)

Prepared by Steve Olson for the National Academy of Engineering of the National Academies

# MAKING THINGS

## 21st Century Manufacturing and Design

SUMMARY OF A FORUM

Prepared by Steve Olson
for the
NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
**www.nap.edu**

**THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001**

NOTICE: The subject of this report is a forum titled Making Things: 21st Century Manufacturing and Design held during the 2011 Annual Meeting of the National Academy of Engineering.

Opinions, finding, and conclusions expressed in this publication are those of the forum participants and not necessarily the views of the National Academy of Engineering.

International Standard Book Number 13: 978-0-309-22559-5
International Standard Book Number 10: 0-309-22559-0

Copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (888) 624-8373 or (202) 334-3313 (in the Washington metropolitan area); online at *http://www.nap.edu*.

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Printed in the United States of America

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*Advisers to the Nation on Science, Engineering, and Medicine*

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# Preface

More than two decades ago, just as I was arriving at the Massachusetts Institute of Technology (MIT), a commission of 17 MIT scientists and economists released a report that opened with the memorable phrase, "To live well, a nation must produce well."[1] Is that still true? Or can the United States remain a preeminent nation while other countries increasingly make the products that once were made in America?

These questions were at the center of a forum titled "Making Things: 21st Century Manufacturing and Design" held during the 2011 Annual Meeting of the National Academy of Engineering. In a wide-ranging and provocative conversation, seven leaders of business, government, and academia explored the many facets of manufacturing and design and outlined the many opportunities and responsibilities posed by manufacturing for the engineering profession.

Craig Barrett, the former CEO and chairman of Intel Corporation and a passionate leader in the movement to improve K–12 education in science, technology, engineering, and mathematics (STEM), described what it will take for America to remain a manufacturing leader in the 21st century.

Rodney Brooks, former head of the Computer Science and Artificial Intelligence Laboratory at MIT and founder-chairman of Heartland Robotics, painted a compelling picture of low-technology products being manufactured by high-technology robots.

[1] Michael L. Dertouzos, Richard K. Lester, Robert M. Solow, and the MIT Commission. 1989. *Made in America: Regaining the Productive Edge*. Cambridge, Mass.: The MIT Press.

NAE President Charles M. Vest presenting opening remarks.

Larry Burns, former vice president for research and development and strategic planning of General Motors Corporation, drew on his experiences at GM—positive and negative—to distill five essential lessons for the next generation of engineers.

Ursula Burns, chairman and CEO of Xerox Corporation, issued a forceful challenge to be "impatient with the status quo" in protecting America's historical strengths.

Regina Dugan, the director of the Defense Advanced Research Projects Agency (DARPA), warned that weaknesses in U.S. manufacturing could threaten national security—"to protect, we must produce."

Brett Giroir, vice chancellor for strategic initiatives at Texas A&M and CEO of the National Biosecurity Foundation, described a particular aspect of protection—the manufacturing of vaccines and treatments to guard against pandemics and bioterrorism.

Finally, David Kelley, founder and chairman of IDEO, highlighted the importance of design thinking—along with individual and institutional confidence—to creativity, innovation, and success.

Ali Velshi, CNN's chief business correspondent, served as a superb moderator for the forum. The partnership between the NAE and Ali benefits us both. The NAE can take advantage of Ali's ability to ask probing questions and lead engaging conversations. And Ali has the opportunity to spend time with people who have thought deeply about engineering. As Ali said, the media "need to find heroic stories about engineering. They exist, but we have to be better at putting them together."

As the nation heads into a presidential election year, manufacturing probably will not be a prominent issue in debates or on television. Yet manufacturing made America strong and will do much to shape its future. As we prepare to make decisions about the policies of this nation, we would all benefit by spending more time talking and thinking about manufacturing.

Charles M. Vest, President
National Academy of Engineering

# Contents

# I

# The Many Facets of Manufacturing

During the first half of the forum, each of the seven panelists identified what he or she saw as the most important issues in manufacturing. Some spoke broadly about manufacturing, while others examined specific topics. But all pointed to the importance of manufacturing and to the need to retain a strong manufacturing base in the United States.

## PREREQUISITES FOR SUCCESS

For manufacturing to take place in the United States, three critical conditions must be met, said Craig Barrett, the former chairman and CEO of Intel Corporation.

First, the individuals involved in manufacturing must add value to the process. For modern manufacturing, adding value requires a solid educational background. "If you want an effective manufacturing, design, and engineering workforce, you have to have an effective education system," said Barrett. Yet the K–12 education system in the United States is "mediocre," according to Barrett. "We're failing in that fundamental aspect. If we're going to talk about anything, it should be the implementation of improvement in the education system."

Second, manufacturing needs to be associated with activities that add value to the process. For example, intellectual property and fast-changing products both add value to manufacturing. Products that are not protected by intellectual property or do not change over time are "a target for the rest of the world." Many of the technologies associated with the Grand Challenges (see Box 1) identified by the National Academy of Engineering are undergoing rapid change, Barrett noted, and are

**Box 1**
**The Grand Challenges for Engineering**

In 2008, a National Academy of Engineering committee released a list of 14 engineering challenges that, if met, could help people and the planet thrive. Many of these challenges have manufacturing components and could lie at the core of vigorous U.S. industries in the future.

1. Make solar energy economical
2. Provide energy from fusion
3. Develop carbon sequestration methods
4. Manage the nitrogen cycle
5. Provide access to clean water
6. Restore and improve urban infrastructure
7. Advance health informatics
8. Engineer better medicines
9. Reverse-engineer the brain
10. Prevent nuclear terror
11. Secure cyberspace
12. Enhance virtual reality
13. Advance personalized learning
14. Engineer the tools of scientific discovery

For more information, see *http://www.engineeringchallenges.org*.

> "If you want an effective manufacturing, design, and engineering workforce, you have to have an effective education system."
> *Craig Barrett*

likely areas for the United States to lead in design and manufacturing.

Third, the right government policies need to be in place. Immigration policy is undermining manufacturing, said Barrett, by making it more difficult for well-trained scientists and engineers to work in the United States. So is corporate tax policy, which is discouraging the construction of manufacturing facilities in the United States. "We need a lot more than talk" about these and other issues, said Barrett. "We need action."

The day after the forum, Barrett was traveling to Portland, Oregon, where Intel has about 15,000 employees involved in design and manufacturing. Their average salary is three times the average for other

Craig R. Barrett, former CEO and chairman of Intel Corporation.

Oregon workers. "If you are involved in the right areas, manufacturing and design are alive and well in the United States." But these three issues need to be addressed for manufacturing to thrive.

## A HIGH-TECH APPROACH TO LOW-TECH PRODUCTS

Engineers are enamored of high technology, said Rodney Brooks, the founder, chairman, and CTO of Heartland Robotics and MIT professor emeritus. But this fascination with the fastest and most advanced technologies should not cause them to overlook the potential inherent in low-technology products. Information technology has had a tremendous run over the past half century. The continual decrease in price and increase in processing power have transformed computers from gigantic machines that ordinary people could not touch to devices that people put in their pockets and briefcases. Computers also have transformed many jobs, making them much more productive. For example, computer-enabled increases in the productivity of office workers have been cited as the main driver of the economic boom of the 1990s.

Manufacturing in the United States still adds $2 trillion of value to products every year—about the same amount of value as is produced by manufacturing in Europe and in China and twice the value produced in Japan. America has maintained this level of added value by moving continually toward the manufacturing of high-value products. The manufacturing of low-value products—which Brooks called "Walmart-class

Rodney A. Brooks, Panasonic Professor of Robotics Emeritus, Massachusetts Institute of Technology.

manufacturing, the fry pans, the stuff that is technologically simple"—generally occurs in other countries. Only in particular areas such as cosmetics, where fashion changes so fast that long supply chains are too slow, is low-value-added manufacturing done in the United States.

The United States loses something by not manufacturing ordinary things in this country. Much valuable innovation in products and processes occurs in the everyday effort to improve manufacturing. "We lose the place where innovation happens," said Brooks.

Information technology now has the potential to change the way people build ordinary, low-tech products. In particular, robotics can "democratize low-end manufacturing," according to Brooks. In most factories today, robots are only cost effective with long-run, high-value goods because they are expensive and complex to build. But when robotics evolves to the point where personal computers are today, ordinary factory workers will be able to program them to do short production runs. Then, all products, whether high tech or low tech, can have short supply chains and quick response times. "If you [manufac-

> "If you [manufacture low-technology products] close to where they are sold, they become fast moving, and you get a lot more innovation happening here in the United States."
>
> *Rodney Brooks*

ture low-technology products] close to where they are sold, they become fast moving and you get a lot more innovation happening here in the United States," said Brooks.

There is tremendous opportunity for information technology to transform low-end manufacturing," said Brooks, and already venture capitalists are starting to invest in the trend. "It's not real glamorous, but there's a lot of impact to be had."

## FIVE LESSONS FOR THE NEXT GENERATION

Design and manufacturing are processes that convert resources into experiences desired by customers, said Lawrence Burns, former vice president for research and development (R&D) and strategic planning, General Motors Corporation. Design and manufacturing thus encompass all facets of a customer's experience, not just the physical product.

Burns outlined five lessons for the next generation that he has distilled from what went right and what went wrong during his time at General Motors.

*1. Manufacturing is an integrated system.*

Manufacturing is a lot more than what goes on in factories. It includes designing, engineering, sourcing, producing, distributing, marketing, and selling products.

The best manufacturers, said Burns, are the ones that do all of these as part of an integrated system. This often requires working across disciplines and beyond walls. Examples of this integrative approach include:

- Simultaneous engineering: the practice of product development such that all aspects of the design phases are considered simultaneously.
- Design for manufacturing: the process of proactively designing a product for low-cost, high-quality manufacturing.
- Math-based design and engineering: for example, computer-aided design.
- Six Sigma quality: a process that uses data and statistical methods to measure and improve the quality of a company's operational performance by identifying and eliminating the causes of defects (with the goal of only two defective outputs per billion) and minimizing variability in manufacturing and business processes.

- The Toyota Production System: a manufacturing methodology/philosophy developed by Toyota with the goal of maximizing value by eliminating waste.
- Supply chain management: the integration of key business processes across the supply chain for the purpose of creating value for customers and stakeholders.
- Life-cycle analysis: a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).

"We must teach the next generation about manufacturing in this broad context," said Burns.

*2. Manufacturers must be driven by customer experiences.*

Customers realize value through their experiences with products and brands. Consistently positive experiences result in greater value, higher brand equity, and superior prices. These positive experiences have to be explicitly designed and delivered in a product.

"When I get asked, 'Why did GM go bankrupt?' I humbly tell people that we lost sight of our purpose, which was to consistently

Lawrence D. Burns, former vice president for research and development and strategic planning, General Motors Corporation.

deliver positive customer experiences. The next generation must never make this mistake."

*3. Manufacturers must grow better beans in addition to counting them.*

Successful manufacturing requires more than effective operations. It also requires a strategy that provides a sustainable advantage. This means embracing innovation, which Burns described as "perhaps the only truly sustainable advantage for manufacturers." He provided a short list of industries that have been disrupted by new technologies or new business models:

> "When I get asked, 'Why did GM go bankrupt?' I humbly tell people that we lost sight of our purpose, which was to consistently deliver positive customer experiences. The next generation must never make this mistake."
>
> *Lawrence Burns*

- Photography
- Media
- Entertainment
- Computer
- Telecommunication
- Television
- Pharmaceutical

When industries are disrupted, the incumbents usually do poorly. "For this reason, I believe the best approach is to do unto yourself before others do unto you," said Burns.

*4. Manufacturing innovation is still quite young.*

Though Burns has witnessed extraordinary developments during his career, the best is yet to come, he predicted. He challenged the audience to consider the possibilities that might follow from recent advances, such as:

- The "materials genome": a public-private partnership that aims to double the speed with which new materials are discovered, developed, and manufactured.
- Nanotechnology
- "Mecha-ma-tronics": the integration of mechanical systems, smart materials, and electronics.
- Wireless integrated microsystems: integrated microsystems capable of measuring or controlling physical parameters, inter-

preting data, and communicating information over a wireless connection.
- Optimized, agile, real-time manufacturing systems: production systems supported by processes, tools, and training that enable manufacturers to respond quickly to customer needs and market changes while minimizing costs and maximizing customer value.
- Digital manufacturing: the use of an integrated, computer-based system comprised of simulation, three-dimensional (3D) visualization, analytics and collaboration tools to define and optimize product and manufacturing process design simultaneously.
- Advanced robotics: devices that act largely, or partly, autonomously; that interact physically with people or their environment; and that are capable of modifying their behavior based upon sensor data.
- High-performance computing: the use of parallel processing to solve advanced computational problems efficiently, reliably, and quickly.
- Intelligent machine-to-machine systems: networks that allow machines to communicate with each other and use relayed information to adapt their actions to accomplish specific tasks in the face of uncertainty and variability.
- The "mobility Internet": the emerging information/communication infrastructure that enables precise coordination of the movement of people and goods; it will do for vehicles what the information Internet did for computers.
- Cradle-to-cradle design, where materials are essentially "leased" rather than consumed.

"I wish I were a 23-year-old engineer looking forward to applying these opportunities to enhance customer experiences. The potential is endless."

*5. Engineers with integrative minds will be the leaders.*

Innovation and engineering are learning processes aimed at reaching market "tipping points" for new ideas, said Burns. Markets tip when customer value is greater than the market price and the market price is greater than the supplier cost. At that point, customers demand new experiences, manufacturers supply them, and transformation occurs at a scale that makes a difference. Engineers with integrative minds focused on designing and delivering innovative customer experiences have the opportunity to lead this process. From Burn's perspective, no other discipline is capable of designing, developing, and validating the integrated systems that will turn tomorrow's science into sustainable and positive customer experiences.

Burns closed by recounting his own transformative experience. "Eighteen years ago, I woke up deaf. Today, I hear with cochlear implants, but what impresses me most about this technology is how the manufacturer of my implants, the Cochlear Corporation, has consistently innovated to enhance my experience. When manufacturers do this right, they create powerful brands, they become formidable competitors, they grow jobs, they prosper."

The next generation needs to recognize that design and manufacturing will continue to be fundamental to our future. "They need to know that these are exciting and rewarding fields that will positively transform how people live their daily lives."

## FOSTERING IMPATIENCE WITH THE STATUS QUO

The United States cannot be successful without a healthy manufacturing sector, said Ursula Burns, chairman and CEO of the Xerox Corporation. That requires a steady stream of talented and well-trained scientists, engineers, and innovators. It also requires an infrastructure and governmental policies that can increase exports and fuel job creation. Whether the nation needs to produce well to live well is a "no-brainer," said Burns. "This is one of the things that we must know, that we should know, and that we shouldn't have to prove again and again."

> "We need to celebrate impatience and make it the virtue by which we do business every day."
>
> *Ursula Burns*

The more important question is whether the United States can generate the will needed to sustain the manufacturing sector. For much of the 20th century, the nation's economic power and quality of life depended on its ability to innovate and manufacture. That combination spawned the automotive industry, the aviation industry, the computer and information technology industry, biotechnology, space exploration, and other sources of groundbreaking products and skilled, high-paying jobs. The potential loss of that capacity is a "Sputnik moment," said Burns. "We've lost sight of that formula for success and we're running out of time to fix it."

Ursula M. Burns, chairman and CEO of Xerox Corporation.

Several obstacles are holding America back, said Burns. Xerox has good jobs for engineers and innovators, but it is having trouble finding suitable candidates to fill those jobs. The country's education system is not producing the well-trained employees needed to do this work, and immigration policy is driving skilled workers out of the country rather than attracting them into the country. Policies on taxation, trade, and intellectual property all make it more advantageous to locate business activities in other countries rather than in the United States.

Xerox is a company that still makes things in America and plans to do so for many years to come, said Burns. Still, manufacturing jobs are becoming increasingly sophisticated, and she worries about the ability of American workers to keep up with international competition.

The United States needs policies that promote rather than stymie trade, according to Burns. Far more people live outside the United States than live in it. Emphasizing the tremendous opportunity of trade can build support for government policies that will further U.S. manufacturing and job creation.

Finally, the United States needs to invest in its manufacturing infrastructure, Burns observed. Manufacturers need to get products to the places where people will buy and use them, which requires a strong transportation infrastructure. Whether the nation needs such an infrastructure is "a silly debate that we should be very impatient about having." America needs to invest for the long term to protect and maintain its historical strengths.

Policymakers and other leaders need to be more impatient with the status quo, Burns said. They should focus on how the nation can create more jobs, not on why the nation is not creating more jobs. They should ask how the nation can compete more effectively while eliminating hunger, poverty, and injustice. "We need to celebrate impatience and make it the virtue by which we do business every day."

## PRODUCE TO PROTECT

Americans today consume more goods manufactured overseas than ever before and are less likely to be employed in manufacturing than at any time in the past century. What does that mean for the nation's defense capabilities? asked Regina Dugan, director of the Defense Advanced Research Projects Agency (DARPA). Even Adam Smith warned that "if any particular manufacture was necessary, indeed, for the defense of the society, it might not always be prudent to depend upon our neighbors for the supply." Perhaps times are different now and the United States will never experience warfare on the scale of the two world wars, Dugan acknowledged, but "perhaps we will."

The innovations that DARPA has pioneered, such as the Internet or the Global Positioning System, have had major consequences not only for national security but also for the United States as a whole. That should not be surprising, said Dugan. The Department

Regina E. Dugan, director, Defense Advanced Research Projects Agency.

of Defense is essentially a mini-society. It has the same problems as the broader society, from health care to communications. Solving problems for that mini-society almost always has implications for the larger society.

The same observation can be made about manufacturing. Manufacturing is fundamental to both national security and economic security. "The question is not whether U.S. manufacturing is essential to our national security [or our] diplomatic and economic health," said Dugan. "The question is how best to revitalize our manufacturing base."

> "The question is not whether U.S. manufacturing is essential to our national security [or our] diplomatic and economic health. The question is how best to revitalize our manufacturing base."
> *Regina Dugan*

Acquisition reform is an urgent need, Dugan insisted. Over the past decade, more than 100 congressional directives, GAO reports, public and private studies, and task forces have addressed the issue. As Norman Augustine, former CEO of Lockheed Martin Corporation, has noted, if current trends in the manufacturing of defense aircraft continue, by the year 2054 the entire Department of Defense budget will be required to purchase one fighter airplane. Quite obviously, that trend is not sustainable. With very few exceptions, complex defense systems undergo increases in unit cost and decreases in the number purchased rather than being canceled. "No healthy industry has such trend lines," said Dugan.

DARPA is not a policy organization in charge of laws or regulations that govern acquisition; but it is heavily involved in the technical means by which defense technologies are made. It plans to spend $1 billion over the next 5 years on manufacturing-related technologies, from metatools for design and simulation to novel manufacturing to putting 1,000 three-dimensional printers in high schools to boost STEM education. "If successful, these efforts could contribute alternative design and production methods for systems spanning ground combat vehicles to vaccine production," said Dugan.

The keys to innovation are speed, number, and diversity. Just as the Internet enabled massive innovation in electronics and information technologies, DARPA is seeking enabling technologies that will spur innovation in manufacturing. In particular, it is focused on high-value-added manufacturing where innovation and unique capabilities offer a competitive edge.

To remain competitive economically and militarily, the nation must innovate, and to innovate, the nation must make things. As Dugan put it, "to protect, we must produce."

## PRODUCE TO LIVE

The 2009 H1N1 epidemic and failing grades in assessments of U.S. biosecurity preparedness have been a "wake up call," said Brett Giroir, vice chancellor for strategic initiatives. The Texas A&M University System, and president and CEO, National Biosecurity Foundation. Manufacturing has become the rate-limiting step for getting new vaccines and treatments to market, including biosecurity products for defense. Giroir suggested that an appropriate addition to the statement "to live well, a nation must produce well" is "to live at all, the nation must produce."

Vaccine production relies on a 60-year-old technology that grows flu virus in chicken embryos. Because the process takes a long time, vaccines to combat H1N1 during the epidemic did not become widely available until a large portion of the population had become infected. As a national security official was quoted as saying, "We did not dodge a bullet. Nature hit us square in the chest, but this time she was shooting a BB gun."

The problem of manufacturing is not limited to vaccines. For example, a growing number of new cancer medications now represent $150 billion of the $850 billion global pharmaceutical market, said Giroir.

Brett P. Giroir, vice chancellor for strategic initiatives, The Texas A&M University System.

These are large and complex molecules that can have tens of thousands of atoms—as complex, compared to a simple molecule like aspirin, as "a business jet is to a bicycle," according to Giroir.

The fundamental problem, he said, is that biological drug manufacturing is stuck in an inflexible paradigm that keeps innovative products from entering the clinical pipeline. Manufacturing facilities have long lead times for design and construction and can cost $500 million to $1 billion to build, but intellectual property protection is relatively short. A factory can make only one product, and because of the nuances of FDA regulations, the factory must be built before the final clinical trial of a product takes place, which means that billion-dollar investments sometimes need to be scrapped.

A consortium led by Texas A&M and supported by DARPA has taken two dramatic steps to change this paradigm. The first is to modularize the manufacturing architecture for pharmaceuticals. Instead of a Taj Mahal, what is needed is a trailer park, said Giroir. The fundamental building block in this paradigm is a modular clean room that is completely self-contained. It plugs into chilled water and power and is on air bearings so that it can be moved. Clean hallways serve as docking stations for individual pods. This architecture has reduced capital costs by an order of magnitude, and construction times are 15 to 18 months. A single facility can accommodate multiple products, and new products can be manufactured by undocking a pod and re-docking one containing the process for a new product. Furthermore, production can be rapidly ramped up by plugging in additional units. "Think about that for biodefense," said Giroir. "If you're attacked, you can switch your entire factory overnight to the product in question to protect the country."

"If you're attacked, you can switch your entire factory overnight to the product in question to protect the country."
*Brett Giroir*

The second major step has been to get rid of the chicken embryos and grow vaccines in plants. A prototype facility has been constructed that can grow more than 2.2 million nicotiana plants, which is a relative of tobacco that can be grown indoors and hydroponically. The facility was designed, built, and brought online within 15 months and, again, at an order of magnitude less cost than a conventional facility. Much work remains to be done to gain FDA regulatory approval, but this one facility has the capacity to produce 100 million doses of vaccine each month at an extraordinarily low cost.

These innovations "will dramatically lower the unit cost and incentivize companies to manufacture in America." Even more important, small companies and universities will have far lower barriers to entry, which will allow a flood of new life-saving vaccines and treatments to enter the marketplace.

## CREATIVITY, CONFIDENCE, AND INNOVATION

David Kelley, founder and chairman of IDEO and Stanford University professor of mechanical engineering, said that his life's work has been to help individuals and organizations with their creative confidence. A lack of confidence and fear of failure is keeping individuals and organizations from doing new things, he said. "That's what's causing us to not innovate."

This loss of confidence starts early. Children are inherently creative, Kelley said. If a classroom of kindergarteners is asked who is creative, everyone raises his or her hand. But by the fourth grade, students start to opt out of being creative. "They say they're not creative, and those muscles atrophy."

Both at Stanford and IDEO, Kelley teaches what he calls design thinking. It is a step-by-step approach that allows people to continuously improve their methods of being creative. The approach teaches people to trust the intuitive side of their brain that synthesizes ideas and experiences. Design thinking is "like fertilizer, water, and sunshine for people who want to create."

David M. Kelley, founder and chairman of IDEO.

The idea has taken off, according to Kelley. The $35 million Hasso Plattner Institute of Design at Stanford is organized around design thinking. Concepts such as agile software, lean start-ups, and 21st-century skills in K–12 education all overlap significantly with the idea.

Design thinking is human centered, said Kelley. What companies really need is to be deeply connected with their customers. Companies may be experts with the products and services they provide, but they also need deep empathy for the people who use those products and services. Recognizing the nonobvious latent needs that lead to breakthroughs can be a "messy" process, said Kelley. But "we do that on a daily basis and it is working."

Another important aspect of design thinking is iterative prototyping. The idea is to build something in a very tentative and unpolished form. Then show it to people and let them improve it. "It is amazing how they will help you. They'll tell you what's wrong with it, and then you can go back and fix it." Kelley terms that approach "build to think," in which showing is a way of thinking.

> Design thinking is "like fertilizer, water, and sunshine for people who want to create."
> *David Kelley*

Finally, design thinking uses what Kelley calls radical collaboration. People often say that U.S. students are the most creative in the world, but that is not true, said Kelley. "What we are is more diverse." By building teams of collaborators consisting of people with different backgrounds, people can build on each other's ideas and come up with solutions that they never would have created if all the members of the team had the same background.

"I'm a mechanical engineering professor," said Kelley. "Five mechanical engineers as a team do not come up with the same ideas as a team with a business person, an anthropologist, a social scientist, an educator, and a mechanical engineer. . . . Putting that diversity to work is a great thing."

Design thinking is helping students, entrepreneurs, and companies design new products and make better decisions. "Building creative confidence in students and in companies is the way to solve the problems we have about not manufacturing and not innovating as much as we did before. . . . When you are confident, you come up with a whole different set of choices, so you make a better decision. . . . That is our 'change the world' strategy."

# II

# From Talk to Action

In the second half of the forum, the panelists responded to questions from Ali Velshi, anchor and chief business correspondent, CNN, and the audience. The conversation ranged widely, but four topics came up repeatedly: job creation, the role of government, the benefits of diversity, and the importance of K–12 education.

## JOB CREATION

At a time of high and enduring unemployment, the creation of jobs was a prominent concern for all the panelists. Manufacturing can provide good jobs, but jobs are not regulated or stimulated into being, said Lawrence Burns, former vice president for research and development and strategic planning, General Motors Corporation. "They're earned by serving customers through the creation of value." Craig Barrett, former chairman and CEO, Intel Corporation, agreed: "The United States in its actions has to want and earn this capability. It is not a native right of the United States to have all of manufacturing."

Technology has given companies the ability to change the structure of a company to reduce waste, said Burns. Reducing waste sometimes cuts the number of jobs without reducing outputs. Similarly, new methods of manufacturing can increase throughput without adding jobs. "The digital economy underlying our physical economy has changed the nature of things."

In addition, technological shifts can affect jobs in unpredictable ways. When General Motors was deciding where to make the lithium-ion batteries for the Chevrolet Volt, it decided that it needed to control the quality of the battery pack, so it assembled the battery modules in

CNN chief business correspondent Ali Velshi and forum panelists.

a plant in Michigan. But it chose a Korean battery cell manufacturer because of their know-how in manufacturing the cells. Also, because a battery-powered vehicle has far fewer moving parts than a combustion engine vehicle, fewer people are needed to design and build such a car. "Battery manufacturing is radically less labor intensive than machining lines would be," said Burns.

Of course, new technology also has the potential to create jobs. Rodney Brooks, founder, chairman, and CTO of Heartland Robotics, and MIT professor emeritus, pointed out that the United States has many thousands of small and medium-sized companies that are involved in manufacturing, and many of these companies are operating the same way they were 50 years ago. New technologies could revolutionize and reinvigorate these companies, returning manufacturing jobs to the United States.

To keep value in the United States, the know-how responsible for creating that value needs to exist here. This know-how is not always in high technologies. As Ursula Burns, chairman and CEO, Xerox Corporation, observed, Xerox wants to build things in the United States but is having trouble in the Northeast finding manufacturing engineers. The United States has "lost the low end—the building of the physical gear boxes and things like that." Once those capabilities are lost to other countries, they can be very hard to get back.

Burns also pointed out that half of Xerox's revenue comes from outside the United States. Xerox therefore can justify opening a plant in another country because the company has as many customers outside the United States as inside it. The real question is what the United States needs to do to attract and retain manufacturing jobs. Deciding where to locate a manufacturing factory is not a social choice, like making a friend, Burns observed. Xerox has to choose the best place to get business done. In that respect, what the company needs is a good infrastructure, a good tax system, and skilled workers. "I sometimes feel guilty, as if I should be employing more people here. Then I have to wake up and say that I'm employing as many people here as I need to get the job done, no less and, interestingly enough, no more." Barrett made essentially the same point, observing that the majority of high-technology companies get more of their revenue from outside the United States than inside the United States. If these companies choose to manufacture their products in the United States, other countries want to know why the manufacturing is not being done in their countries.

Lawrence Burns urged the forum attendees not to overlook the importance of design. Apple's market capitalization now exceeds that of Toyota, Daimler, and Ford combined, he said, despite the amount of capital required to be in the auto business. Apple is "an enormous innovator," and its products "clearly delight people."

Apple's history reveals another lesson. Not every idea is going to work. As Burns pointed out, people need to accept the idea that failures will occur. Dugan said that one of the reasons DARPA has been successful is because its program managers are encouraged to succeed big, and when they are pushed in that direction, leaders must not fear failure. "Failure is not the problem. Fear of failure is the problem."

## THE ROLE OF GOVERNMENT

Velshi pointed out that solutions to many current problems already exist. But a sense of paralysis obstructs action, and usually that paralysis is associated with government.

The steps that government needs to take are clear, said Barrett. It should institute a permanent R&D tax credit, a reasonable immigration policy, a tax structure conducive to innovation and manufacturing, and supportive policies in areas such as education and trade. It is counterproductive for the public sector to be "driving companies out of the United States and then vilifying them for doing what makes sense," Barrett said. "We're not serious. We have not chosen, as a country, to compete. We talk about it, but we have not chosen to compete because we have not taken the actions necessary to compete."

How to overcome this paralysis was a prominent concern of the panelists. Ursula Burns observed that it is not possible for either government or business to solve most big problems, like energy, on their own. But to work with business, government needs to be constructive and fast-moving. "I don't know if we are structured as a government to do that," Burns said. If government cannot help, then business must do what it can do. "Let's help one kid at a time, one school at a time, and one area at a time."

One way to generate movement would be to have more scientists and engineers in government, and the panelists discussed how this might happen. Ursula Burns noted that the financial returns from being a lawyer, a doctor, or a banker are much greater than the financial returns from engineering, especially during the early portions of their working lives. Since it takes a lot of money to run for Congress, that is a barrier for engineers. Also, lawyers are trained to argue positions, whether they believe in that position or not. "Engineers' brains are not wired that way," she said.

Lawrence Burns agreed that the thought processes are very different. In the policy world, the questions are poorly defined, the data are messy, the methodology rarely fits, and there is usually more than one right answer. "We're wired a little bit differently than politicians, [but] it doesn't mean we can't have a big impact." Meeting with staff is very useful, he said. Staff may be poorly trained to deal with some of the technical subjects with which engineers deal. But engineers have know-how and need to disseminate that know-how to people who are making policy decisions.

Brett Giroir, vice chancellor for strategic initiatives, The Texas A&M University System, agreed that, based on his experiences at DARPA and now in a university setting, the people to try to influence first are the permanent staff in Congress. They inform the legislative agenda to a large degree. Also, by getting more technical people onto these staffs, it would be possible to integrate that knowledge into decision making, "and, quite frankly, that's where the money and the programs originate."

Regina Dugan, director, Defense Advanced Research Projects Agency (DARPA), said there are various reasons why scientists and engineers are not more engaged, but the important question is how they can engage more through a variety of mechanisms. DARPA, for example, brings scientists and engineers into the agency for 3 to 5 years. It is their "contribution and their service to country." DARPA tries to use the perspectives of scientists and engineers to inform difficult questions and debate through a structured analytical process. DARPA also pays a great deal of attention to how to communicate these issues to people who are not experts in the subject matter. "We have to be able to communicate in a way that is understood to non-subject-matter experts. We have to treat communication as a discipline."

In addition, people can serve their country in different ways, Dugan noted. DARPA recently conducted some large-scale data analysis in support of forward operations in Afghanistan. It discovered, said Dugan, that what was needed was "25-year-old kids who breathe data like we breathe air." Many of these individuals were graduate students who felt compelled to serve their country. However, when they joined the military, they lost their fellowships, and DARPA had to go back and restore their fellowships one by one. "If you see something like that happen in your university, fix it," said Dugan.

## THE BENEFITS OF DIVERSITY

Dugan and David Kelley, founder and chairman of IDEO and Stanford University professor of mechanical engineering, elaborated on their remarks about diversity and innovation during the question-and-answer session. Diversity can take different forms, said Dugan. For example, diverse people, diverse technologies, and diverse cognitive approaches can all spur creativity. An example of technological diversity is when people began to use personal computers to do programming, resulting in an explosion of software engineering, she observed. The same thing is beginning to happen with the production of pharmaceuticals as approaches become more modular and decentralized.

Diverse cognitive approaches can be even more productive. As an example, Dugan cited the recent success of Foldit. Nature's rules for protein folding are extremely varied and complex, yet how a protein folds is crucial to the action of biological molecules and plays a role in many diseases. High-power computers have been used to determine how proteins fold, but even computers cannot predict the structures of many proteins. Several years ago, a group of researchers at the University of Washington created a protein-folding game called Foldit, which exposed challenges in protein folding to hundreds of thousands of non-experts. People who turn out to be savants at protein folding have become involved—"you would have never known, 15-year-old kids, 43-year-old marketing executives." In 2011, Foldit players deciphered in 10 days the structure of a protein involved in AIDS in rhesus monkeys that had defied solution for 15 years. "It's that kind of speed to innovation and advance that I think we can hope for as we dramatically increase the number and diversity of people who are participating," said Dugan. "In almost all situations, cognitive diversity trumps ability from the perspective of creating innovative ideas."

Kelley described a comparable process at the Hasso Plattner Institute of Design at Stanford, where teams of students, doctors, lawyers, business people, engineers, and educators work together on problems. The engineers tend to be process leaders but tend not to lead the entire team, said Kelley. However, they could be team leaders, he added, if they received leadership training in the same way that business schools and law schools teach leadership skills as a part of their curricula.

## THE IMPORTANCE OF K–12 EDUCATION

Finally, K–12 innovation is the fundamental base on which success is built, the panelists observed. Today, the bright spots in education, said Barrett, are magnet schools or charter schools outside the existing system. Because they are less bound by entrenched bureaucracies, they are more able to innovate. These schools can in turn leverage change in the rest of the system. "You have to get in at the local level and create centers of excellence," he said. "[You have to] show what can be done if you have competent teachers, high expectations, and short feedback loops to help struggling students and teachers."

Dugan pointed out that the ideas behind Foldit can be extended to teaching—for example, to teach young students fractions. "It's not gaming for the sake of gaming. It's very purposeful." By working their way through various pathways, students can find the best way to learn fractions. Furthermore, individual students who are learning this way can inform the larger discussion about the diverse strategies needed to learn many topics. Every keystroke, every place in the game a student visits, each occasional frustration or success is recorded and can lead to real-time modification of the game.

Students who receive individualized tutoring learn at a much accelerated rate compared with typical classrooms, Dugan observed. Tech-

Member participation in a group discussion.

nology tools and interactions with games now provide what amounts to individualized tutoring.

Hands-on experience can also make the difference in a student's life, Kelley said. Early in his career, every student in mechanical engineering at Stanford had torn apart a car or redesigned a bicycle. Now they are more likely to be computer experts, but most are still interested in design. Getting students involved in large-scale projects can build on that interest. For example, if high school students are told that they have to maintain a C average to work on a solar car project, they tend to bring up their grades in all subjects so they can participate. Projects "that get kids involved with doing things with their hands result in them being turned on to innovation," said Kelley.

Dugan, too, emphasized the importance of inspiration. Many of today's scientists and engineers were inspired by the hard but compelling challenge of the moon shot. "It became an intellectual challenge, something to engage in."

Businesses can help inspire and support students and teachers. Ursula Burns observed that the leader of a corporation can decide what is important and people will align behind that decision. Companies can "set a tone that says that education is important, and we can back that tone with money." Companies also can allow their engineers, scientists, finance people, and other employees to get engaged with education on a local level. She suggested that members of the NAE find some students, some school administrators, "anybody who will listen and start . . . solving the problem that way." Changing education is slow, steady work, but "the work is not going to be done by anyone but us, so we have to get to it." As Barrett said, a small deed done is better than a great deed planned.

Barrett also emphasized the importance of working at the systems level. For example, only about two-thirds of all math teachers have content expertise in the subject, which means that virtually all students will have a math teacher without a firm grasp of the subject at some point from kindergarten through high school. "It's a perfect filter," observed Barrett. Teach for America and charter schools are trying, in different ways, to address this problem, and their efforts need to be supported.

Also at the systems level, the adoption of the internationally benchmarked common core standards for mathematics, language arts, and, soon, science by every state in the nation would establish a set of goals suitable for every student. "That's a key to the United States education system going forward, and the governors are the key to making it happen," Barrett said.

## THE GLOBAL EFFECTS OF LOCAL ACTION

Thinking globally and acting locally remains the best way of attacking these problems, said Charles Vest, NAE president, in summing up the forum. Engineers focus on the here and now even as they attempt to solve problems that can be global in scale. These problems can be daunting, but engineers have the tools and knowledge needed to solve them. "There's never been a more exciting time."

# Appendix A

# Forum Agenda

**Annual Meeting Forum**
**Making Things: 21st Century Manufacturing and Design**

Monday, October 4, 2010
9:30 am – 12:30 pm, Eastern Daylight Time
JW Marriott Hotel
Washington, D.C.

Twenty years ago, as the U.S. consumer manufacturing sector suffered a near-death experience in the face of Japanese innovations, the MIT report *Made in America* concluded that, "To live well a nation must produce well." Is this still true today? What now lies ahead in this world of globalization, open innovation, biology-based manufacturing, and next-generation robotics? How do we inspire and educate students to create the next wave of design and manufacturing breakthroughs? What will be the ramifications for jobs in the United States?

Welcome
**Charles M. Vest**, President, National Academy of Engineering

**Moderator: Ali Velshi**, Anchor and Chief Business Correspondent, CNN

## Forum Discussion

*Forum Participants:*

**Craig R. Barrett**, Former Chairman and CEO, Intel Corporation
*The Realities of High-Tech Manufacturing: Location and Employment*

**Rodney A. Brooks**, Founder, Chairman, and CTO of Heartland Robotics, and MIT Professor Emeritus
*The Coming Role of Robotics in Reinvigorating 21st Century Manufacturing*

**Lawrence D. Burns**, Former Vice President for R&D and Strategic Planning, General Motors Corporation
*What the Next Generation Needs to Know and Do in Manufacturing and Design*

**Ursula M. Burns**, Chairman and CEO, Xerox Corporation
*Manufacturing: The Forward View from the Helm of a Global Consumer Products Company*

**Regina E. Dugan**, Director, Defense Advanced Research Projects Agency (DARPA)
*How to Dramatically Shrink the Time from Concept to Product*

**Brett P. Giroir**, Vice Chancellor for Strategic Initiatives, The Texas A&M University System, and Executive Director of the National Center for Therapeutics Manufacturing
*Biomanufacturing: The Next Frontier*

**David M. Kelley**, Founder and Chairman of IDEO and Stanford University Professor of Mechanical Engineering
*Designing Products for Real People*

# Appendix B

# Biographical Information

**ALI VELSHI** executes several roles across CNN as the network's chief business correspondent, anchor of *Wake Up Call*, host of *Your Money*, and host of the "Ali V" podcast. In addition to his anchor responsibilities, Velshi frequently reports from the field on breaking news events, politics, and in-depth personal profiles that offer insights into national issues. In 2010, he covered the impact of the oil disaster in the Gulf of Mexico, including exclusive access with the U.S. Coast Guard on a controlled oil burn. He has extensively reported on the global financial meltdown since 2008; the financial collapses of Fannie Mae, Freddie Mac, AIG, and Lehman Brothers; the U.S. government's bailout plan; and the battle over the fate of the nation's big three automakers.

Velshi's in-depth reporting for CNN's "How the Wheels Came Off" was honored with a National Headliner Award for Business & Consumer Reporting in 2010. He anchored CNN's breaking news coverage of the attempted terror attack on a flight into Detroit, for which the network was nominated for a 2010 Emmy. He was also honored with a 2010 Alumni Achievement Award from his alma mater, Queen's University.

Previously, Velshi was an anchor with the business news channel CNNfn, where he hosted various interactive shows, including *Your Money*, *Business Unusual*, *Insights*, *Street Sweep*, and *The Money Gang*. Before joining CNNfn in 2001, he hosted *The Business News*, Canada's first and only prime-time business news hour, airing nightly on *Report on Business Television*.

Earlier in his career, Velshi worked as a business anchor for Cable Pulse 24 and sister station CITY TV in Toronto, and as a reporter for CFTO-TV in Toronto—Canada's most watched local television station.

In 1996, Velshi was awarded a fellowship to the U.S. Congress by the American Political Sciences Association, and worked with now-retired U.S. Rep. Lee Hamilton (D-IN).

Born in Kenya and raised in Toronto, Velshi graduated from Queens University in Kingston, Ontario, in 1994 with a degree in religion. Velshi's first book, *Gimme My Money Back: Your Guide to Beating the Financial Crisis*, was released in January 2009. He is a member of the Grand Challenges Advisory Committee for the National Academy of Engineering, the Economic Club of New York, and the New York Financial Writers Association.

**CRAIG R. BARRETT** was chairman of the board of Intel Corporation until May 2009. He successfully led the corporation through some

of its worst times, including the burst of the "dot-com bubble" and a severe recession. Dr. Barrett began his career with Intel in 1974 as a manager. He was promoted to a vice presidency of the corporation in 1984; to senior vice president in 1987, and to executive vice president in 1990. In 1992, Dr. Barrett was elected to Intel's Board of Directors and was named chief operating officer in 1993. He became Intel's fourth president in May 1997 and its chief executive officer in 1998. In May 2005 he became chairman of the board. After retiring from Intel, Dr. Barrett joined the faculty at Thunderbird School of Global Management in Glendale, Arizona.

From 1998–2005 he was a member of the Hong Kong Chief Executive's Council of International Advisers. He joined the board of trustees of the Society for Science and the Public in 2010, in which year he also became the co-chair of the Skolkovo Innovation Center in Russia. He now serves as president and chairman of BASIS School Inc., one of the nation's leading charter school groups.

Dr. Barrett is a member of the National Academy of Engineering. On June 3, 2008, he was honored by the Novosibirsk University with the title Doctor during a ceremony in Akademgorodok for the cooperation between Intel and the university. Along with the title he received the Golden Badge of the Siberian Branch of the Russian Academy of Sciences. He received the Robert Lansing Hardy Award of the Minerals, Metals & Materials Society in 1969. He and wife, Barbara, received the

Woodrow Wilson Award for Corporate Citizenship on January 31, 2006, in Phoenix, Arizona, from the Woodrow Wilson International Center for Scholars. In addition, Dr. Barrett holds a Datukship, an honorary Malaysian title akin to a knighthood.

Dr. Barrett is the author of more than 40 technical papers dealing with the influence of microstructure on the properties of materials and authored a textbook on materials science titled *The Principles of Engineering Materials*, which remains in use today.

Barrett attended Stanford University from 1957 to 1964 and received his Ph.D. in materials science. During his time at Stanford he joined the Kappa Sigma Fraternity. After graduation, he joined the Stanford University Department of Materials Science and Engineering and remained there until 1974. Dr. Barrett was NATO Postdoctoral Fellow at the National Physical Laboratory in England from 1964 to 1965. He was also a Fulbright Fellow to the Technical University of Denmark in 1972, working with Professor Rodney Cotterill.

Seemingly as a testament to his career in higher education, Craig and his wife gave a $10 million endowment to Arizona State University in 2000, resulting in the institution naming their Honors College after the couple.

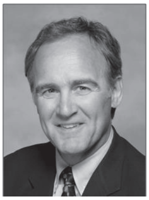
**RODNEY A. BROOKS** is the Panasonic Professor of Robotics (Emeritus) at Massachusetts Institute of Technology (MIT). He is a robotics entrepreneur and founder, chairman, and CTO of Heartland Robotics Inc. He is also a founder, board member, and former CTO (1991–2008) of iRobot Corp. Dr. Brooks is the former director (1997–2007) of the MIT Artificial Intelligence Laboratory and then the MIT Computer Science & Artificial Intelligence Laboratory (CSAIL). He received degrees in pure mathematics from the Flinders University of South Australia and a Ph.D. in computer science from Stanford University in 1981. He held research positions at Carnegie Mellon University and MIT and a faculty position at Stanford before joining the faculty of MIT in 1984. He has published many papers in computer vision, artificial intelligence, robotics, and artificial life.

Dr. Brooks serves as a member of the International Scientific Advisory Group of National Information and Communication Technology Australia, and on the Global Innovation and Technology Advisory Council of John Deere & Co. He is an xconomist at Xconomy and a regular contributor to the *Edge*.

Dr. Brooks is a member of the National Academy of Engineering, a founding fellow of the Association for the Advancement of Artificial Intelligence, a fellow of the American Academy of Arts and Sciences, a fellow of the American Association for the Advancement of Science, a fellow of the Association for Computing Machinery, a corresponding member of the Australian Academy of Science, and a foreign fellow of the Australian Academy of Technological Sciences and Engineering. He won the Computers and Thought Award at the 1991 IJCAI (International Joint Conference on Artificial Intelligence). He has been the Cray Lecturer at the University of Minnesota, the Mellon Lecturer at Dartmouth College, and the Forsythe Lecturer at Stanford University. He was co-founding editor of the *International Journal of Computer Vision* and is a member of the editorial boards of various journals, including *Adaptive Behavior*, *Artificial Life*, *Applied Artificial Intelligence*, *Autonomous Robots*, and *New Generation Computing*. He starred as himself in the 1997 Errol Morris movie "Fast, Cheap and Out of Control" named for one of his scientific papers, a Sony Classics picture, available on DVD.

**LAWRENCE D. BURNS** is currently a professor of engineering practice at the University of Michigan and director of the Roundtable on Sustainable Mobility at Columbia University's Earth Institute. His focus at both institutions is energy policy and transportation. He is also a senior advisor of CleanTech at VantagePoint Venture Partners.

Previously he was global process leader for research and development (R&D) and planning at General Motors Company (formerly Motors Liquidation Company). Burns joined GM at age 18, under a program in which he studied for an engineering degree at General Motors Institute (now Kettering University) in Flint, Michigan; students alternated every six weeks between their studies and work at the company. His scholarship was sponsored by GM's research laboratory (the lab he later ran as head of R&D), and he went on to earn a master's degree in engineering and public policy from the University of Michigan and a Ph.D. in civil engineering from the University of California at Berkeley. During his 40-year career at GM, Burns played an increasingly central role in the company's many innovations and experiments in auto technology and design. Dr. Burns served as vice president of R&D and strategic planning at General Motors Corporation from May 1998 to July 2009.



His vision is explained at length, and richly illustrated, in *Reinventing the Automobile: Personal Urban Mobility for the 21st Century* (MIT Press, 2010), which he coauthored with Christopher Borroni-Bird and the late William J. Mitchell.

Dr. Burns is a member of the advisory council of Greentech Capital Advisors and serves as a director of Midwest Research Institute Inc. He serves as a member of the Automotive Strategy Board of General Motors and is a senior adviser to the chairman of Hess Corporation. He serves as a trustee at Rochester Institute of Technology. Dr. Burns is a contractor at the U.S. Department of Energy's National Renewable Energy Laboratory.

**URSULA M. BURNS** is chairman and chief executive officer of Xerox Corporation. Ms. Burns joined Xerox in 1980 as a mechanical engineering summer intern and later assumed roles in product development and planning. From 1992 through 2000, she led several business teams including the office color and fax business and office network printing business. In 2000, she was named senior vice president, Corporate Strategic Services, heading up manufacturing and supply chain operations. She then took on the broader role of leading Xerox's global research as well as product development, marketing, and delivery. In April 2007, Ms. Burns was named president of Xerox, expanding her leadership to also include the company's IT organization, corporate strategy, human resources, corporate marketing, and global accounts. At that time, she was also elected a member of the company's Board of Directors. Ms. Burns was named chief executive officer in July 2009 and assumed the role of chairman of the company on May 20, 2010.

In addition to the Xerox board, she is a board director of the American Express Corporation. Ms. Burns also provides leadership counsel to community, educational, and nonprofit organizations including FIRST (For Inspiration and Recognition of Science and Technology), National Academy Foundation, MIT, and the U.S. Olympic Committee, among others. Ms. Burns was named by President Barack Obama to help lead the White House national program on STEM (science, technology, engineering, and math) in November 2009 and was appointed vice chair of the President's Export Council in March 2010.

Ms. Burns earned a bachelor of science degree in mechanical engineering from Polytechnic Institute of New York University and a master of science degree in mechanical engineering from Columbia University.

**REGINA E. DUGAN** was sworn in as the 19th director of the Defense Advanced Research Projects Agency (DARPA) on July 20, 2009.

Founded in 1958 as a response to the Soviet Union's launch of Sputnik, DARPA's mission is to prevent and create strategic surprise. From its founding more than 50 years ago to current day, this mission implies one imperative for the agency: radical innovation for national security. Today, DARPA is the principal agency within the Department of Defense for research, development, and demonstration of high-risk, high-payoff projects for the current and future combat force.

Experienced in counterterrorism and defense against explosive threats, Dr. Dugan first served the nation as a DARPA program manager from 1996 to 2000. She directed a diverse $100 million portfolio of programs including the Dog's Nose program, which focused on the development of an advanced, field-portable system for detecting the explosive content of land mines. In 1999, Dr. Dugan was named DARPA Program Manager of the Year and, in 2000, she was awarded the prestigious Bronze de Fleury Medal by the Army Engineer Regiment. Other recognition includes the Office of the Secretary of Defense Award for Exceptional Service and the Award for Outstanding Achievement.

Dr. Dugan's contributions to the U.S. military are numerous. She led a counterterrorism task force for the deputy secretary of defense in 1999 and, from 2001 to 2003, she served as a special advisor to the vice chief of staff of the Army, completing a Quick Reaction Study on Countermine for Enduring Freedom. The results of this study were subsequently briefed to joint senior military leadership and implemented in the field.

Prior to her appointment as director of DARPA, Dr. Dugan co-founded Dugan Ventures, a niche investment firm, where she served as president and CEO. In 2005, Dugan Ventures founded RedXDefense LLC, a privately held company devoted to innovative solutions for combating explosive threats, where she also served as president and CEO.

Widely recognized for her leadership in technology development, Dr. Dugan has appeared on CNN, the Discovery Channel, National Public Radio, and *The AAAS Science Report;* has been featured in *The*

*New York Times*, *The Wall Street Journal*, *Prism*, *Forbes*, and *Science News*, among others; and has delivered keynote remarks at events as diverse as All Things Digital (D9), AIA (Aerospace Industries Association) Board of Governors' meeting, Defense Manufacturing Conference, and SPIE Defense, Security, and Sensing. In 2011, she was named a Tech Titan by *Washingtonian Magazine*. Dr. Dugan previously participated in wide-ranging studies for the Defense Science Board, Army Science Board, National Research Council, and the Science Foundation, and sat on the Naval Research Advisory Committee and the Defense Threat Reduction Agency and Technology Panel.

Dr. Dugan obtained her doctoral degree in mechanical engineering from the California Institute of Technology, her master's and bachelor's degrees from Virginia Tech, and in 2011 she was awarded an honorary doctorate of science from California State University, Fullerton, only the 16th such honorary degree given since the university's founding in 1957. She is the sole inventor or co-inventor on multiple patents and patents pending. Dr. Dugan is the co-author along with J.B. Jones of *Engineering Thermodynamics* (Prentice-Hall, 1996). She is the first female director of DARPA.

**BRETT P. GIROIR** is the vice chancellor for strategic initiatives for the Texas A&M University System. He is responsible for leading efforts that are critical to the development of the biotechnology initiatives within the A&M System and the emerging biotechnology corridor. Dr. Giroir also serves as executive director of the Institute of Innovative Therapeutics, a single, unified biomedical enterprise designed to improve global health through research, development, demonstration, and commercialization. He is president and chief executive officer of the National Biosecurity Foundation, a coalition of academic and industry partners advancing research, education, and economic development within the state of Texas and throughout the United States.

Prior to this position, Dr. Giroir was the Texas A&M University System vice chancellor for research. He came to the A&M System from DARPA, where he was director of the Defense Sciences Office from 2006 to 2008; from 2004 to 2006, he served as deputy director of that office. Prior to DARPA, Dr. Giroir served as associate dean for clinical affairs, University of Texas (UT) Southwestern Medical Center, and chief medical officer, Children's Medical Center Dallas. He began his professional career with the UT Southwestern

Medical Center (Dallas), as an assistant professor and ended his work there as the Associates First Capital Corporation Distinguished Chair in Pediatrics.

Dr. Giroir received his B.A. magna cum laude from Harvard University and his M.D. from UT Southwestern Medical Center (Dallas). He completed his residency in pediatrics at the Children's Medical Center Dallas and Parkland Memorial Hospital and did a clinical fellowship in pediatric critical care at UT Southwestern Medical Center. From 1991–1993 he was a research fellow at the Howard Hughes Medical Institute in Dallas.

**DAVID M. KELLEY**, founder and chairman of IDEO, is a California-based entrepreneur, educator, designer, and venture capitalist. He is recognized as one of America's leading design innovators, in part thanks to his membership in the National Academy of Engineering and his receipt of numerous awards. Mr. Kelley serves as the Donald W. Whittier Professor in the Product Design Program at Stanford University, where he also established the school's Hasso Plattner Institute of Design, also known as the d.school. Preparing the design thinkers of tomorrow earned Mr. Kelley the Sir Misha Black Medal for his "distinguished contribution to design education." He has also won the Edison Achievement Award for Innovation, as well as the Chrysler Design Award and National Design Award in Product Design from the Smithsonian's Cooper-Hewitt National Design Museum.