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Editors’ Note

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Engineering, Technology, and the Future of Work

Anyone who caught an episode of Mad Men—or worked in an office in the 1970s—can easily see how technological developments have changed the workplace. Rows of typists transcribing documents from Dictaphones were replaced by personal computers and word processing software used directly by their would-be bosses. In factories, computer-aided design and manufacturing replaced the reams of paper used to encode machining instructions for each part via holes punched in the paper tape, along with the drafters and tape encoders who prepared the part drawings and machining instructions by hand. These developments enabled huge improvements in productivity and cost savings, and also transformed how work was done and what types of jobs were available.

The evolution of work, enabled by engineering advances, continues today. Developments in machine learning, computer vision, and compliant actuators, for example, allow robots to work alongside people in factories, hospitals, and retail stores; autonomous vehicles to travel across the country with little input from human drivers; and IBM’s Watson to predict the health outcomes of patients with chronic diseases. These advances will affect the ways that engineers, pharmacists, storekeepers, truckers, and many others approach their work in the coming years.

In Washington DC, responses to these technological developments and their potential influence on the future of work range between fascination and mild panic. In just the past few months, more than a dozen policy forums have raised the question of whether robots and other automated technologies will destroy jobs; one Washington Post columnist called it the “Great Robot Freakout of 2015” (Rampell 2015).

There are several good reasons to pay attention to the impact of technological innovations on the workplace and jobs. Employment growth rates in production, sales, and office administration occupations have generally been sinking since the 1980s, a decrease attributed to the falling costs of automating routine, codifiable tasks. Employment growth in the manufacturing sector has largely been driven by demand for workers with four-year or graduate degrees, while the long-term availability of jobs for less educated workers has declined. And these trends predate the recent recession, meaning that they are likely to continue even after the economy fully recovers.

Unfortunately, too often what is lost in the national conversation on technology and human capital is the recognition that we—engineers, policymakers, educators, and business leaders—have the ability to influence this dynamic from both sides. We have a role to play in creating a system where people can more easily gain the education and skills needed to work with advancing technologies, thus improving job prospects for a larger share of the population. And by encouraging the design of machines that not only are easy to use but actively help workers contribute additional value to the job—while at the same time automating tasks that are dangerous or boring—we support improved workplace conditions that better complement people’s skills.

The articles in this issue consider the many roles of engineers in shaping the future of work: through the technological systems they design, the business opportunities they identify, the students they educate, and the
resources they create to facilitate learning throughout one’s career.

In the first article, Jennifer M. Miller examines the potential impacts of autonomous vehicles on employment and the nature of work in occupations that require driving. By analyzing detailed data on activities performed on the job, she categorizes occupations into those that may be open to more people as vehicles become more automated, those that may be eliminated, and those that can incorporate more value-added activities in place of driving (think school bus drivers who help students learn while in transit). These categories can help both employers and workers anticipate how job requirements are likely to change, and can help autonomous vehicle makers understand what types of features to design into the vehicles to accommodate the changing nature of work in different occupations.

Chris Johnson explains how changing business models in industrial infrastructure, such as power generation, transit, and manufacturing plants, are shifting the role of companies that provide these systems and the engineers that work for them. As industrial infrastructure providers offer more services to support engineering design, operations, and financing over the lifecycle of the systems they produce, these product-service systems require engineers who can model the performance of an infrastructure system over its life, diagnose the system’s condition based on observed data, and identify opportunities for solutions that improve the efficient use and value of the system over time.

Educating students for the changing nature of work is the focus of an article by Katharine G. Frase, who examines possible approaches for K–12 and college pedagogy as well as the use of data to enable personalized guidance for learners. She explains the need for partnerships between employers, educators, and government to craft curricular content that keeps pace with the evolving knowledge and capabilities needed for current and emerging careers.

John A. Alic examines workforce adaptability beyond formal education. He posits that informal learning—for example, through on-the-job experience and online educational content—is increasingly important as technological change reshapes the labor market. To help people gain additional skills and make career changes, he advocates for the creation of new institutional structures and tools to support “just in time” learning.

The last of our invited articles illustrates the role of public-private partnerships in helping both communities and companies prosper amid technological change. Dan Swinney describes three national and international examples of regional collaborations that promote workforce and economic development in the manufacturing sector. He makes the case that coalitions of small businesses, schools, research institutions, labor, and government are effective in spurring the growth of regional economic clusters that develop large numbers of both thriving small businesses and well-paid jobs.

The theme of this issue was inspired by the NAE’s Manufacturing, Design, and Innovation (MDI) program. We are proud to be part of a team that, as part of that program, was charged by the NAE to examine how technological advances, new business models, and intensifying globalization are transforming manufacturing and high-tech value chains. The results of the team’s first year and a half of work are presented in NAE’s report on Making Value for America: Embracing the Future of Manufacturing, Technology, and Work (NAE 2015; available at www.nap.edu). The NAE is launching a second phase, on “Educating the Engineering and Technical Workforce for Resiliency to Change,” that will examine educational and organizational approaches to improve the ability of the workforce to adapt to technological changes.1

We thank all the authors and staff who contributed to this special issue, especially Managing Editor Cameron Fletcher.

References


1 The NAE point of contact for the project is Amelia Greer (AGreer@nae.edu).
Autonomous vehicles can improve safety and enhance worker efficiency both on the road and on the job.

**Autonomous Vehicles**

*Implications for Employment Demand*

Jennifer M. Miller

Autonomous vehicle (AV) technology, popularly envisioned as “driverless cars,” has reached maturity and the cusp of commercialization (RAND 2014; Urmson 2015). Attention has turned to the many policy issues raised by such vehicles on public roads (Beiker 2012; Khan et al. 2012). Reports have largely focused on the use of autonomous vehicles for commuting; less attention has been paid to how they will be used on the job. Yet businesses may be early adopters of AV technology, as an extension of existing forms of workplace automation.

The business case for adoption of AV technology is strong. Most of the more than 35,000 annual traffic deaths in the United States involve driver error (RAND 2014), and the National Highway Traffic Safety Administration (NHTSA 2003) estimates that on-the-job motor vehicle accidents cost US employers almost $55 billion each year.\(^1\) Furthermore, as explained below, in addition to saving lives and reducing insurance costs, lost work time, and property damage, autonomous vehicles will save labor. Industry, affected workers, policymakers, and those preparing the future workforce should therefore consider the potential impacts of autonomous vehicles on employment.

Data from the Department of Labor (DOL) and the Bureau of Labor Statistics (BLS) indicate which occupations are likely to face the biggest changes.

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\(^1\) In 2015 dollars, based on data from 1998–2000.
Economic Perspectives on Automation

Economists view automation as a substitution of capital for labor in a production process. When capital becomes less expensive relative to labor, production processes tend to rely more on automation and less on human labor. The level of substitution varies by industry (Arrow et al. 1961).

With widespread adoption of autonomous vehicle technology, many vehicle trips may no longer require a human driver.

When labor and capital are substitutes, if capital becomes less expensive, fewer workers will be employed and they will be paid less. For example, if a road improvement reduces travel time between two cities, drivers will be employed for fewer hours to conduct the same level of trade. Even if trade increases, the reduction in hours due to improved conditions may still outweigh the benefits of the increased trade.

More recently, economists have looked at how technology complements, rather than substitutes for, certain types of high-skilled labor (Acemoglu and Autor 2011). For example, by increasing workers’ productivity, personal computers increased employment and earnings of workers with complementary skills. Consider the effect of computers on the employment of quality control analysts: as computers facilitate measurement, data analysis, and communication, workers with complementary skills may be hired and better compensated to do quality control work in more settings.

Potential Employment Effects of Autonomous Vehicles

To understand how AV technology will affect employment, it is helpful to look at the tasks and work activities associated with specific occupations (Autor et al. 2003).

Driving has typically been seen as a manual, non-routine task and therefore not very amenable to automation. With the maturity of AV technology, it may be time to revisit that assumption. NHTSA describes vehicle automation along a continuum ranging from level 0—all functions are controlled by a human driver—to level 4—the vehicle can drive itself. Employment may begin to be significantly affected at level 3, where automation allows the driver to safely do other work.

With widespread adoption of AV technology, many vehicle trips may no longer require a human driver. And for those that do, the work activities and required skills and abilities will change.

Occupational Data on Driving as a Work Activity

The Occupational Information Network (O*NET; www.onetonline.org) is the US government’s official source of information about occupations, with data from surveys of workers, occupational experts, and occupational analysts. Collected under the sponsorship of the DOL and based on the Standard Occupational Classification, the data include detailed descriptions of the tasks, work activities, and tools (a category that includes vehicles) used in each occupation. It is thus possible to focus on occupations that use relevant types of vehicles and examine possible employment impacts from the adoption of AV technology.

Several elements of the O*NET database may be useful for identifying occupations that are likely to be affected by AV technology. Of particular interest, the description of each occupation’s work context includes the extent to which work takes place “in an enclosed vehicle or equipment.” Occupations are scored from 0 to 100 based on responses on a scale from “never” to “every day.”

Scores are similarly assigned for the importance and level of activity involved in “Operating Vehicles, Mechanized Devices, or Equipment” based on a scale that assigns points for “operate a car” (approximately 30 points), “drive an 18-wheel tractor-trailer” (approximately 60), and “hover a helicopter in a strong wind” (approximately 85). This analysis focuses on 85 occu-

2 Tasks and work activities are two elements of the six-part Occupational Information Network (O*NET) content model used to describe occupations. Tasks are occupation-specific and work activities cross occupations.

3 The O*NET scales include watercraft, airborne vehicles, and manufacturing equipment; these are not relevant to this analysis, which focuses on jobs that use vehicles suitable for travel on public roadways. All discussion and analysis in this article are specific to occupations likely to operate vehicles on public roads.
pations that score above 50 on both the operating vehicles importance scale and the enclosed vehicle work context scale.

The potential for substitution and complementarity between capital-intensive AV technology and the labor of human drivers raises a host of questions about impacts on the workforce. Which workers are likely to lose their jobs? For which jobs will driving no longer be a required skill, increasing the labor pool from which these workers could be recruited? Which complementary skills will be in greater demand if autonomous vehicles become widely adopted? Which occupations and regions are most likely to be affected?

To frame discussion of these questions, this analysis classifies occupations into four types: drivers, visitors, hosts, and teams (table 1). The typology differentiates between occupations in which driving is the primary work activity and those in which it is an important but secondary work activity. In either case, the autonomous vehicle can be a substitute for or a complement to the worker’s labor.

**Classification of Occupations**

Occupations likely to be significantly affected by adoption of AV technology are those that place a high importance on operating vehicles and those that involve working regularly in an enclosed vehicle. O*NET data make it possible to illustrate the categories of occupational vehicle use, as shown in table 2.

The four types—driver, visitor, host, and team—are described more thoroughly in the following sections, which include the criteria used to define each type; a representative example occupation; likely labor market effects, including competition and skill requirements; and expected technical challenges and opportunities for incorporating autonomous vehicles into the type of occupation.

**Drivers**

For this category of occupation, driving is the primary task, typically done under routine conditions and with few other tasks, none of which require a high level of skill. A representative job in this category would be pizza delivery driver; others might be heavy and tractor-trailer truck drivers, couriers and messengers, and refuse and recycling collectors.

In these jobs there is little opportunity for the human driver to add value either in transit or at the worksite, so the jobs might be fully automated, removing the human driver from the occupation entirely. For example, Amazon has filed a patent application (number 14/502707) for an unmanned aerial vehicle delivery system, informally referred to as an “Amazon drone.”

If driving becomes a fully automated activity, capital could substitute for labor almost completely in these

---

**TABLE 1 Typology of potential impacts of autonomous vehicles on employment. See text for definition of terms.**

<table>
<thead>
<tr>
<th>Substitute</th>
<th>Complement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Drivers:</strong> Human driver adds negligible value and may be fully replaceable.</td>
<td>Hosts: Human may add value in transit once relieved of routine driving duties. May require training or staffing for complementary skills.</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Visitors:</strong> Human driver adds value at the worksite but has little potential to add value in transit. These occupations may appeal to more workers once driving is no longer required.</td>
<td>Teams: Human member of the “team” has skills that can be used to add value in transit. May benefit from incorporating complementary technology into the vehicle.</td>
</tr>
</tbody>
</table>

**TABLE 2 Representative examples of occupation types that involve operating vehicles and may be affected by autonomous vehicle technology.**

<table>
<thead>
<tr>
<th>Substitute</th>
<th>Complement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Drivers:</strong> Light truck or delivery services driver</td>
<td>Hosts: Bus drivers, school or special client</td>
</tr>
<tr>
<td>Importance = 81, Level = 51</td>
<td>Importance = 87, Level = 58</td>
</tr>
<tr>
<td>Enclosed vehicle = 90</td>
<td>Enclosed vehicle = 100</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Visitors:</strong> Pest control workers</td>
<td>Teams: Emergency medical technicians and paramedics</td>
</tr>
<tr>
<td>Importance = 84, Level = 48</td>
<td>Importance = 82, Level = 66</td>
</tr>
<tr>
<td>Enclosed vehicle = 99</td>
<td>Enclosed vehicle = 89</td>
</tr>
</tbody>
</table>

Note: Importance and level scores refer to importance of driving and skill level of driving required. Enclosed vehicle score refers to frequency with which the work context is in an enclosed vehicle or equipment. Scores are scaled from 1 to 100.
occupations. Technical aspects of incorporating autonomous vehicles would focus on automating all additional tasks, such as identity verification in the case of a delivery worker, that are currently performed by the human driver. Without a human driver, these vehicles could be optimized for cargo space, fuel efficiency, and other criteria.

**Visitors**

Visitor occupations may involve a lot of time driving and place a high importance on the ability to drive, but the driving is routine and the worker’s productive activity takes place at a worksite. Representative occupations in this category are pest control workers, heating and air conditioning mechanics and installers, and tree trimmers or pruners.

The visitor’s opportunity to be productive while in transit is minimal. Assuming the work performed onsite is not routine enough to be automated, visitor jobs would still require a human worker to travel from site to site, but that worker would no longer need to be willing—or perhaps even able—to drive a vehicle as a significant work activity. These occupations would then be open to workers now excluded because of the driving requirement, whether for legal, health, or personal preference reasons.

For onsite work that requires a relatively low skill level, current workers may have been selected in large part for their driving ability. They should expect to face more labor market competition if autonomous vehicles are widely adopted.

The technical aspects of adapting autonomous vehicles for these occupations may depend on whether the workers are self-employed. If they are, these aspects may involve entertainment amenities for enjoyment between jobs. For firms that employ workers in visitor occupations, technical aspects are likely to balance risk management by monitoring employee activity in the vehicle (e.g., the presence of unauthorized passengers, substance use) with amenities (e.g., entertainment systems, food service) that may be incorporated to cost-effectively improve employee retention and engagement.

**Hosts**

In host occupations, driving is the primary work activity. Some of it may be nonroutine. Representative occupations in this category are school bus drivers and other bus or shuttle drivers for schools, airports, and special clients, such as tour guides.

Workers in these jobs are typically selected based on driving skill and their attention is fully occupied with driving. With an autonomous vehicle, there would be an opportunity for the worker to add value in transit. A program in Hartsville, South Carolina, suggests an intriguing possibility (Chaltain 2015): As part of a school development program, school bus drivers were trained in the basics of child development. The program led to a 71 percent reduction in disciplinary referrals and other positive outcomes for students, families, and teachers. This program clearly demonstrates that if the bus is largely autonomous, school bus drivers can be trained or selected for their ability to work with children, turning travel time into learning time.

**TABLE 3** Top ten occupations likely to be significantly affected by autonomous vehicle technology, by number of employees and occupation type.

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Number of employees</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy and tractor-trailer truck drivers</td>
<td>1,625,290</td>
<td>Driver</td>
</tr>
<tr>
<td>Construction laborers</td>
<td>852,870</td>
<td>Visitor</td>
</tr>
<tr>
<td>Light truck or delivery services drivers</td>
<td>797,010</td>
<td>Driver</td>
</tr>
<tr>
<td>Police and sheriff’s patrol officers</td>
<td>638,810</td>
<td>Team</td>
</tr>
<tr>
<td>Electricians</td>
<td>566,930</td>
<td>Visitor</td>
</tr>
<tr>
<td>Bus drivers, school or special client</td>
<td>499,440</td>
<td>Host</td>
</tr>
<tr>
<td>First-line supervisors of construction trades and extraction workers</td>
<td>496,370</td>
<td>Visitor</td>
</tr>
<tr>
<td>First-line supervisors of mechanics, installers, and repairers</td>
<td>434,810</td>
<td>Visitor</td>
</tr>
<tr>
<td>Driver/sales workers</td>
<td>405,810</td>
<td>Team</td>
</tr>
<tr>
<td>Plumbers, pipefitters, and steamfitters</td>
<td>372,570</td>
<td>Visitor</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>6,689,910</strong></td>
<td></td>
</tr>
</tbody>
</table>

Workers in host occupations should be prepared for changing skill demands. The technical aspects of adapting autonomous vehicles for these occupations would likely involve the addition of features related to skills that the affected workers do not currently use, providing some opportunity for creativity and innovation but also introducing the potential need to develop new skills.

**Teams**

In the team category, the worker and vehicle have complementary “skills and abilities” to achieve high productivity. Driving is an important skill but not necessarily an everyday work activity. Workers are typically selected based on a skill other than driving, although lack of ability or willingness to drive is likely to exclude someone from the job. If automation frees these workers from driving, they will be able to use their current skills productively while in transit.

Representative occupations in this category are ambulance drivers, emergency medical technicians (EMTs), and paramedics. The category might also include criminal investigators and special agents, real estate sales agents, and park naturalists.

With sufficient automation of the transportation infrastructure, including networked communication to traffic signals and other vehicles, emergency response vehicles could be highly autonomous. EMTs and paramedics would be free to prepare for the emergency situation on the way to the site and care for patients while transporting them to the hospital. Workers in these occupations should prepare for more intense labor market competition, increasing skill requirements, and potentially greater labor market demand due to enhanced productivity. For example, the ability to fully staff an ambulance with one person could enable greater coverage in rural areas or during off-hours.

The technical aspects of introducing autonomous vehicles in team occupations would focus on maximizing worker productivity while in transit. Adaptations could include the incorporation of considerable additional technology into the vehicle, to the point that the vehicle functions effectively as an office, medical facility, or lab.

**Size and Distribution of Employment Effects of Autonomous Vehicles**

Data from the BLS Occupational Employment Statistics (OES) make it possible to quantify the number of US workers and identify the states most likely to be affected by autonomous vehicle use.

Based on May 2014 estimates, approximately 11.3 million workers, representing 9 percent of total employment, are in one of the 85 occupations likely to be significantly affected by autonomous vehicles. Ten occupations account for almost 60 percent of those 11.3 million employees (table 3).

Variations in regional economies will also determine the effects of autonomous vehicles on employment. Figure 1 shows that potentially affected workers are most concentrated in states with low population density.

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4 Data from the May 2014 BLS OES estimates (available at www.bls.gov/oes/). Self-employed workers and four occupations with no clear mapping from O*NET to the OES are excluded from this total.
where extractive industries make up a significant part of the economy, based on a location quotient (LQ) that measures such concentration. A higher LQ indicates a higher share of potentially affected workers than the state’s total labor force. North Dakota, Wyoming, and West Virginia are the states with the highest LQs.

A breakdown of occupations in the three most affected states shows that workers in the driver and visitor categories will bear the brunt of the impacts of AV technology (figure 2). In contrast, California has the lowest LQ, with a smaller share of potentially affected workers in the extractive sector and comparatively more in law enforcement and light truck and delivery services.

California’s low LQ may at first seem surprising, since the state has been at the forefront of developing and testing autonomous vehicles. But analysis of the data suggests that, although the commuting benefits of autonomous vehicles are attracting attention in big cities on the coasts, the occupational impact may be greater in the Mid- and Mountain West: although individuals are highly motivated to avoid complex and congested urban driving, rural driving may be easier to automate.

Additional Considerations

There are three main considerations to keep in mind to put this very preliminary, even speculative, analysis in context. First, it is specific to the United States. The impact of autonomous vehicles will be global, and other countries, such as Singapore, may lead in adoption (Land Transport Authority 2015). The extent to which capital substitutes for labor will vary with the makeup of a national economy (Arrow et al. 1961), and this will likely apply to the adoption of autonomous vehicles as well.

Second, it is difficult to disentangle the potential effects of autonomous vehicles from other types of industrial automation. This difficulty manifests in two ways. In a practical sense, with existing occupational data it is not always possible to distinguish the operation of road-based delivery or transport vehicles versus agricultural or industrial equipment. Although the O*NET data on “tools” used in each occupation include type...
of vehicle used (e.g., cars, light trucks or sport-utility vehicles, and minivans or vans), they seemed incomplete and so were used for confirmation and clarification only. It would be useful for future occupational surveys to ask specific questions about driving as a work activity and vehicles as tools and technology. This information would be useful to understand how occupations may change at this new frontier of workplace automation.

More broadly, it is possible that other forms of automation will render autonomous vehicles irrelevant. For example, widespread adoption of e-learning and telecommuting might drastically reduce the need to transport large groups of children to school on a regular basis. The school bus driver may lose out to e-learning rather than to the self-driving bus.

Third, this analysis cannot account for new occupations that may emerge—for example, in the building, management, and maintenance of autonomous vehicle systems. But it also suggests some ways in which a wide variety of jobs might be transformed with the adoption of autonomous vehicles: Demand for certain transportation and delivery work may be drastically reduced with the advent of fully autonomous vehicles. Jobs that involve skilled or manual labor performed at multiple or remote worksites may no longer involve driving as a significant work activity, thus expanding the labor supply. These effects may be particularly strong in rural states with extractive economies.

Finally, some skilled workers may find that their autonomous vehicle includes occupation-specific technology to enable them to maximize productivity while in transit. Other workers may find that they must develop additional complementary skills to remain competitive once driving becomes a less marketable skill.

Conclusion

There are two important reasons to continue examining the occupational impacts of AV technology. Knowledge of these effects can foster innovation by revealing industrial and geographic market opportunities. The earliest adopters of mobile phones, for example, were people with specialized occupational needs. AV technology may follow a similar path.

Better information about the occupational effects of this technology is also important for workforce planning. As manufacturing became increasingly automated and moved offshore, many US workers and communities lost their productive roles in the economy and are still struggling to recover. With improved information and foresight, governments, educational institutions, and individuals can make better labor market decisions as autonomous vehicles improve safety and autonomy both on the road and on the job.

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Chaltain S. 2015. A town where a bus is more than a bus. New York Times, February 27.


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6 Vehicles were not always listed as tools for some occupations for which other O*NET data show that driving is a frequent work activity. For example, no vehicles are listed as tools used by real estate sales agents, although the work context is scored 93/100 for “in an enclosed vehicle or equipment.” The database was helpful in identifying occupations for which the person drove a vehicle or only operated industrial or construction equipment (e.g., with a listing of “Light Trucks and SUVs”).
Engineers can make new value in a slow-growth or lower-margin environment by identifying customer operational and financial risks, then providing performance-based solutions.

Creating New Value with Performance-Based Industrial Systems Design and Operations Management
An Engineering Opportunity

Chris Johnson

In today's slower-growth developed world many firms are experiencing reduced demand, in part because of the emergence of new providers of goods and services entering the market with lower pricing and margins. “Old school” original equipment manufacturers (OEMs) and their engineering professionals are faced with a vitality challenge: How can they energize customers, build excitement about their company, and enhance their ability to create value-driven growth?

There are internal and external systemic opportunities to enhance productivity-driven growth with a number of methods that engineers and their organizations can use to harness deep domain experience, hardware design, performance-based services, software, and financial management to unlock value in complex industrial ecosystems, improve the firm's competitive position, and trump “cheaper” in the market (NAE 2015, pp. 68–70).

This article presents a framework for industrial solutions that create economic value with new investments, growth, and the ability to overcome margin pressure. The discussion is biased toward customer-facing constructs, but the same approaches work internally.

The framework builds on the concept of bundling as an approach to growth. With knowledge of a customer’s operation and the provision of new physical, digital, financial, and operating means to improve industrial infrastructure along with guaranteed key performance indicators or
outcomes, service providers can manage certain customer responsibilities better than the customers can themselves with respect to cost and risk. This can be achieved by bundling insight, hardware, operations decision support software, finance, and a performance guarantee that transfers risk to the provider. Bundling allows organizations to improve operating metrics; develop clear methods to identify and create measurable new productivity and price the risk of achieving it; create service contracts that specify how performance optimization will be achieved, measured, and managed; create shared long-term incentives to co-innovate; and plan for comprehensive solutions that provide “one-stop shopping” for customers, including financing.

Assuming Operational Risk to Cause Growth: Traditional and Equity-Based Transactions

Customers are seldom foolish with respect to acquiring the capital goods and related services that OEMs offer. For fungible goods from OEMs with well-understood and achievable performance (i.e., low risk), a traditional commercial transaction is differentiated by price, integrity, relationships, and reliable services. Where there is acknowledged risk in production, service, or operations, customers usually seek a ratio of financial risk and return from a new investment. If what an OEM offers is not known to a customer, or is not core to the customer’s expertise, a performance-based partnership can be shaped to transfer operational and financial risks to the OEM.

As shown in figure 1, a traditional industrial infrastructure transaction is characterized by an asset offered to and purchased by a customer with capital funds (secured internally or financed) and then operated in their value chain. The provider (typically an OEM) and customer deploy experts to separately focus on engineering design, process design (for use of the asset), operational decision making, financing, and general management. Once transacted, the provider is out of the customer operation (until service or parts are required) and is generally not aware of the extensive interactions and financial incentives needed for operational productivity.

An equity orientation is typically assumed by the customer who is exposed to market demand, competitive substitutions, price pressure, and operational risks arising from the use of the firm’s resources. The financial reward for managing these can be significant—as can the losses. As the (OEM) service provider chooses to shift to an equity orientation, assuming responsibility for infrastructure lifecycle design, operations, and finance, it can include co-optimized economic performance and flexibility in its commercial offering because the risk and value management incentives are available to do so, as explained below.

In a slow-growth commercial setting, a forcing function that a provider can choose is to cause an operational

<table>
<thead>
<tr>
<th>Performance Risk Scale</th>
<th>Risk</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transaction</td>
<td>1</td>
<td>Materials warranty</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Commercial</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Availability, reliability</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Service repairs</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Models fidelity</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Ops decision support</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>KPI performance</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Credit</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Residual</td>
</tr>
<tr>
<td>Equity</td>
<td>10</td>
<td>Financial</td>
</tr>
</tbody>
</table>

FIGURE 1  Transaction-equity risk transfer continuum, including commercial, operational, and financial risk. Providers with less involvement fall on the “transaction” side of the spectrum and assume less risk. As providers assume more types and levels of risk by offering value-added performance-based solutions, they increase their exposure to financial variances and move toward the “equity” side of the spectrum. KPI = key process indicator; OEM = original equipment manufacturer; Ops = operations.
performance risk shift. Co-optimized engineering design and operations, coupled with financing, align the incentives of the provider, the consumer in mature industrial system verticals (e.g., in rail transportation, power generation, health care, aviation), and their manufacturing ecosystems. At the intersection of asset design and operations, productivity gains can reduce a high percentage of operating costs and thus cause an incremental customer impact at a lower cost than through traditional new product introduction (NPI).

An example is a rail network customer operations optimization solution (Vantuono 2015) that required more than a hundred million dollars to develop but saves the customer several hundred million dollars per year in operations expense (Norfolk Southern 2010). This can contrast with investment in a hardware NPI design feature that also costs several hundred million dollars to effect and produces several hundred thousand dollars of customer productivity. Both operations optimization and hardware design investments meet financial hurdle rates, yet if there is a need for new growth and margins are under pressure, a shift to the right of the transaction-equity scale of figure 1 is a means for a provider to differentiate faster with a higher return on equity and enhance customer productivity at lower risk to that customer.

**Creating Real Option Value for Sustained and Reliable Cash Flow**

Aircraft engines, power generation systems, locomotives, manufacturing plants and their supply chains, oil exploration, and healthcare systems—and the ecosystems that use them—all exist to perform a service that creates economic value, and their owners want a healthy ratio of risk and return.

Industrial value creation almost always involves the growth of free cash flow (FCF) (Stickney et al. 1991) from the use of assets over an economic life. The created FCF value is based on both present and future design and operation optimization. Future (uncertain) cash flows (of period n) are discounted to an approximate present value (PV) according to the ascribed risk (r) of achieving future cash flow (Brealey et al. 2013). The PV of future cash flow benefits minus the cost of required investments in hardware, services, and operational optimization decision support are a well-established economic metric called net present value (NPV). NPV is sensitive to the discount rate of reconciling future risk and so, just as it is important to find new productivity value, it is also important to reduce the risk in industrial systems operations of attaining that productivity in the future.

\[
PV = FCF_n \left[ \frac{1}{(1 + r)^n} \right] \\
NPV = PV - Investment
\]

Because forecasting is notoriously difficult, discount rates can be high. Value may thus also be ascribed to optionality, the flexibility designed into the hardware and operational decision support. Optionality is best understood in terms of improving the total probability of realizing value. There is nearly always extra upfront cost to add features now that enable industrial systems to have future operating flexibility. These features are real options (Mathews et al. 2007) because they make it possible to switch the design or operation of the asset(s) when conditions change.

Traditional FCF scenario—based accounting cannot be used to establish the value of the extra costs to build in flexibility. Multiple designs and operating points must be simulated and replicated for input variables (e.g., fuel cost, weather, interest rates) whose values vary independently. One option is to build in the capability to pursue future scenarios with the customer by including the ability to expand production, efficiently shut down or retire assets, or change what the industrial system does. These options will free up cash flow if the paths for which the optionality was designed come to pass.
There are tremendous risk reduction and value management benefits when flexibility is incorporated upfront into the design and operations optimization of an industrial system. The job of the service provider’s systems engineer and performance contract underwriters is to create both NPV and flexibility option value, especially when the provider is guaranteeing performance or outcomes over a long period of time.

The Business System Structure of Value Creation
A customer’s and an OEM’s industrial operations are likely to be complex and customized, having evolved to adapt to the technical, risk tolerances and competitive forces of their industry. To identify new economic value or reduce risk for a customer, OEM, or domain, a provider must first recognize and address the limiting factors in a business ecosystem (Johnson 2014).

It is very important to build trust with the customer in order to get to joint identification of value-reducing constraints and variance drivers. This trust will involve a deep understanding of the value creation structure and its constraints that either or both the customer and provider are working to solve. The constraints change over time and the relationship evolves to pursue new value, typically by a provider designing, configuring, and financing hardware and providing ongoing operations optimization and maintenance. In a slow-growth world with emerging substitutes this is a proactive path for a firm to create new value (GE 2012, p. 11).

Without an ability to understand and change the dynamics of the business ecosystem, there is limited prospect for growth and new value creation. Engineers do well with dynamic systems, and these business “physics” are an extension of the engineering mindset.

Figure 2 illustrates a business system framework to build customer trust, identify value, and keep focus on addressing specific causal factors that may constrain value as the latter change through time. There is a central dynamic value creation structure composed of a “virtuous cycle” and a number of constraints or risks to that value. Ideally, in the value creation structure there is an economic surplus in the form of (1) ready capital that accrues from ongoing commercial activity. That capital is invested (2) in improving the firm’s capabilities as measured with key process indicators (KPIs) to (3) provide more attractive offerings. This, in turn, increases profitable business (4), which improves the rate of capital attainment. The virtuous cycle repeats and the rate of new value (1) is increased.

In some cases, however, there may not be novel ideas that are feasible for investment (5), or capital structure may limit the ability for investment (6), or some potential investments may fall below a payback hurdle rate. “Below the line” value creation possibilities may be opportunities for another party, such as (7) a service provider and its investors. Alternatively, a lack of capacity in people or skills leads to poor execution (8) in developing the great ideas a firm does have, or if there is ample capacity, its inefficient application of resources (9) limits value. Finally, a market (and the customers therein) may not understand the offered product or solution, or a significant number of customers may have an incumbent such as a lower-cost provider, or the value proposition may not be real and thus the potential for adoption is limited (10) for industrial investment. Alternatively, it may be that a market segment would adopt but the contact, knowledge building, and trust rate (11) are low.

In addition to these factors, firms have biases that either result from an underlying structure or have contributed to its formation over time. These biases may have led to certain comparative strengths or weaknesses, and it is helpful to take account of them to understand and frame industrial solutions that reinforce strengths or address constraints.

A creative bias is associated with an abundance of valuable ideas for growth, and the system constraint may be a lack of capital or ability to execute these ideas or to reach customers who can and will act on them. A firm may be strong in the execution of projects but lack ideas or marketing. Trade-biased firms may be well branded but have weak order fulfillment. And a firm that views the commercial world as a fixed pie may be more likely to forgo valuable partnerships (e.g., with a service provider or a historical competitor).

Alignment of structural constraints and biases with proposed solutions for creating value and reducing risk
FIGURE 2  Framework for a dynamic business system structure and its specific value creation constraints, which can be identified and acted upon through time by one or more stakeholders seeking to create new financial vitality. CapEx = capital expenditure; KPI = key process indicator; OpEx = operational expenditure.

<table>
<thead>
<tr>
<th>Value point</th>
<th>Aspect</th>
<th>Value creation, risk reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Financial value created</td>
<td>Operations margin, net income, free cash flow level at a point or interval in time. Negative variance to plan history is risk to that created value.</td>
</tr>
<tr>
<td>2</td>
<td>Investment made</td>
<td>Investment in people, plant, and equipment at a point or interval in time.</td>
</tr>
<tr>
<td>3</td>
<td>Business KPI outcomes</td>
<td>Key process indicators at a point or interval in time that differentiate product or service or system performance leading to growth. Examples include throughput, inventory, expense, fulfillment.</td>
</tr>
<tr>
<td>4</td>
<td>Revenue/growth metrics</td>
<td>Increase in orders or other metrics (e.g., clicks, views, use) at a point or interval in time.</td>
</tr>
<tr>
<td>5</td>
<td>Feasible project candidates</td>
<td>Projects that are feasible for one or more stakeholders to budget and cause to happen at a point or interval in time.</td>
</tr>
<tr>
<td>6</td>
<td>Rate of CapEx/OpEx available</td>
<td>Rate and amount of investment available from a stakeholder (owner of a fleet or plant, or a service provider to owner).</td>
</tr>
<tr>
<td>7</td>
<td>Alternate ideas or investors</td>
<td>Service provider who can generate ideas and/or provide capital.</td>
</tr>
<tr>
<td>8</td>
<td>Resources available</td>
<td>Resources (people, assets, space, information) able to execute when applied.</td>
</tr>
<tr>
<td>9</td>
<td>Rate of effective action</td>
<td>Rate at which resources can be effectively applied in value-added tasks.</td>
</tr>
<tr>
<td>10</td>
<td>Qualified prospects</td>
<td>Potential customers or users of a service.</td>
</tr>
<tr>
<td>11</td>
<td>Rate of adoption</td>
<td>Customers who know about or can learn about a product or service and are disposed to act or purchase.</td>
</tr>
</tbody>
</table>
can help a firm better focus its efforts and uncover new opportunity.

Following are examples of problems engineers can address through their understanding of dynamical and systemic structures (Sterman 2000):

- New ideas, or the ability to integrate or exploit new ideas and technology, are lacking.
- Improvement opportunities with favorable returns are hampered by lack of effective organization to get projects up and running (or keep them running).
- Work with other firms that provide comparative value is limited by a lack of trust, or the “fixed pie paradigm,” limiting otherwise valuable partnerships to the role of commoditized vendor.
- A quantitative operations measurement system for performance attribution and risk disposition is needed to lower performance risk and enable collaboration between firms that would not otherwise have the trust or relationship to do so.
- The customer is unaware of constraints for which the provider can shape a solution.
- Ongoing technical services require specialized knowledge and tooling (which may, for example, be more attainable in a focused and shared internal service or offered as a commercial service through contractual agreements for maintenance and operations).

**Digital Simulation to Optimize Industrial System Design and Operations**

Creating value requires a means to discover where risks and returns reside in a complex industrial ecosystem. Using an example from power generation, the modeled ecosystem includes the power market, its commercial structure, operating constraints (e.g., emissions, transmissions, water, capitalization), plant apparatus, operations decisions, control, service, and finance (figure 3). A digital twin simulation model of the industrial ecosystem’s physical and operational dynamics is needed to find and manage risk and value by increasing both NPV and option value. The model will simulate the physical assets, the processes that use and consume them, and the exogenous variables that affect both the asset performance and operational decision support. Optimality may be set as the design and operational set points that maximize NPC and minimize variance from plan.

As a digitally orchestrated, simulated twin of the actual plant—with design, operating scenarios, and replications that account for exogenous variations in input assumptions—the system can be computed in an optimization loop to test new designs and operations policy. The aim is to identify trapped value, enable asset sales, and/or shift the performance risk per the terms of a service solution, including the provisions for investments in new capital assets or modifications to existing industrial systems.

**Risk Attribution**

As commercial relationships shift from transactional to equity-based, different risks—usually related to asset and operational performance—shift from the customer to the OEM.

Asset performance risk is best characterized as meeting the engineering specifications for efficiency and availability. Operational risk is best thought of as the business and physical system’s ability to achieve KPIs, service levels, and financial results. Other risks may involve credit and residual value when financing is involved.

If a customer is transferring responsibility to a service provider so that it may focus its people and available capital on other aspects of its business system, then a performance-based solution very likely has value. At the end of an agreed-upon period, perhaps quarterly, the net financial results of the transferred risk are accumulated for a net payment.

The most difficult risks to structure are performance-based solutions concerning combined design, financing, and operational risks, not only because these can be separately complex but also because of interaction effects. For example, a power plant may not achieve its financial plan for a variety of reasons: an inefficiency in a key physical system or a suboptimal lineup; a poor bid; high fuel costs relative to plan; unexpected maintenance resulting from operations choices that differentially consumed asset life; curtailment of operations because of an exceeded emissions limit; ambient conditions unfavorable to efficient production; lower than anticipated asset use; unavailability of the asset at a high revenue opportunity; or flawed underwriting models related to the performance solution.

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1 Such a shift may occur because there are limited OEM growth prospects from a customer base that is under duress or because of a devolution of pricing power in a market segment due to new entrants that offer assets at a lower cost.
FIGURE 3  Simulation of a power plant’s physical design and operational business system for risk and value management. Simulation of thousands of combinations of asset designs and operational decision policies tied to the subsystems—trade and dispatch, design modifications, operations, control, service, and finance—leads to robustly optimized creation of higher net present value (NPV) for more scenarios. For trade and dispatch, the task is to characterize market participants, production demand, terms, pricing, and own operations costs + line-ups. For design modifications, suggest custom modifications and uprates to plant(s) that meet financial constraints. For operations, find losses of value and risk drivers, actively line up plant, and manage performance attribution. For control, dynamically manage apparatus for real-time optimality, not exceeding long-term damage drivers. For service, characterize how major capital parts are consumed and manage over economic life, set current workscopes. For finance, optimize for lifecycle risk and value: bid, dispatch, operations, control points, services scope, and capital structure. This example may be thought of as a “digital twin” of a plant design and its customer’s operations, from which it is possible to calculate and determine interventions for design and operations management subsystem sensitivities (through the service offering). Ideally, the NPV for all probabilities of outcomes/key process indicators (KPIs) is improved. This change in performance may be underwritten and offered as a performance-based solution to customers, including the financing of upgrades for productivity and flexibility, thus enabling commercial activity where otherwise there would be none (or less) or it would be limited to a discussion of price alone.
A very robust and transparent performance attribution system is needed or a contractual calamity will almost certainly result.

Because the paradigm is long term and depends on co-innovation for a shared gain, there must be a mechanism to calculate performance attribution. There must also be a means of disposition responsibility when operating performance is not achieved, whether because of a service provider's inaccurate models; exogenous conditions that exceed the contractual range (e.g., temperature, airborne particulates, load); a customer's operating decision that does not follow the operational decision support recommendation; and/or some aspect of the system that failed for unforeseen reasons. When outcomes fail to meet expectations, the presence of a robust and fair measuring system enables an honest relationship.

In the attribution tree shown in figure 4, a first branch bifurcates for exogenous factors (e.g., temperature, humidity) that may differ from those specified in the contract. Taking the "in" ("yes") path, the next causality of performance risk is the asset model's accuracy to simulate the physical dynamics. Assuming it is accurate, the decision support is taken or not; if taken and the industrial system does not meet performance, it is the service provider's liability.

Engineering's contribution to making new value is particularly strong in the modelling of physical assets and their use in customer operations, and in the systemic management of risks and returns. The causal factors must be understood first, then a robust performance attribution measuring system must be conceived that is mutually agreeable, followed by rigorous mapping to financial results. These activities are more suited to the skills and tools of the engineering community than the accounting community.

**Physical and Business Systems Dynamical Modelling: An Internal View That Flows Externally**

For physical apparatus, engineers use first principles modelling to efficiently attain new design points for production and operations; a few obvious modelling examples are computational fluid dynamics, thermodynamics, materials, manufacturability, and control.

Emerging paradigms such as reduced-form and data-driven models (as in prognostics) build pattern recognition and provide the ability to characterize the health and performance of assets using data both observed and derived from simulations. Engineers also specialize in industrial simulation, operations research, and optimization of one or multiple aspects of the physical and business system.

Lifecycle models that discretize complex industrial assets into their key components and each asset’s use in customer operations are needed to find and calculate variable expenses. System of systems models orchestrate an asset's design and operations models and reveal opportunities to challenge design points for enhanced manufacturability and lifecycle economic performance once customers use these assets.

Three initiatives illustrate GE's research focus to address design-make-operate aspects of industrial systems that traverse internal and external operations: Brilliant Factory, Digital Twin, and Industrial Internet (also called the Internet of Things, IoT) (figure 5).

Brilliant Factory aims to improve the design–product development cycle time, manufacturing, and supply chain throughput and to reduce inventory and expenses, improve service levels, and increase product quality. It integrates industrial apparatus design tools, supply chain and manufacturing-production capability, and factory operations optimization. It provides physical designs that can meet targets for operating specification, should-cost and manufacturing throughput, inventory, expense, and fulfillment.

Digital Twin, illustrated in figure 6, integrates physical asset design(s) into the lifecycle customer operational design to optimize efficiency, reliability, control, operations, services, and financial performance, all of which then inform new product development, uprates to assets that are currently in service, and new services offerings such as performance-/outcome-based solutions. Combining OEM physical design knowledge with customer operations, Digital Twin seeks to enhance operating productivity and enable performance-based commercial optimization in part by augmenting monitoring and diagnostics to achieve maintenance productivity.

Predix is a platform for integrated data acquisition, security, data storage, analytical orchestration and microservices, user experience, mobile connectivity, and distributed computing that hosts data and computationally intense applications. When combined, these are solutions that can be marketed using business models (from purchased or licensed software) for outcome- and consumption-based performance services.
FIGURE 4 Risk attribution tree used to assign performance results of an industrial system design and operational decision support. Working through this model allows customers to determine whether responsibilities are an appropriate risk to assume or a liability that should be passed on to a provider. Green indicates accuracy and compliance with the automated decision support. Yellow indicates that there is a model error, but with human intervention or a change in exogenous conditions the end result may still be favorable. Red indicates a loss from the plan. The state indicators may be customer or provider centric. KPI = key process indicator.
**Investing to Enable Improvements**

One aspect of internal investment in a “brilliant factory” or external investment to upgrade a customer’s operations is a need for capital today to change the system performance for higher cash flow tomorrow. Internal financing is well understood in business operations and financial services. Less understood are performance solutions that enable the implementation of an upgrade or service maintenance with financing and then realize income as use of the asset is recognized in customer operations.

Various risks in a performance-based contract are associated with investments such as those outlined above (under Risk Attribution). But with a system designed to enable asset monitoring and operations optimization, many risks are reduced and made attributable—and thus open the possibility to asset and operations financing by the OEM or a financial services entity. This embedded or bank financing, which activates new value, requires careful underwriting, monitoring, and management that would most likely be beyond the scope of scalable banking services but would be activated by the OEM/service provider’s participation and risk acceptance.

Uncovering an idea that leads to industrial system value creation is not the same as being able to invest in it. For power plants, wind farms, rail transportation, healthcare delivery, oil and gas extraction, and aviation, powerful engineering tools such as the Digital Twin identify specific opportunities for modifications, uprates, control, and operational decision support. Projects in these areas may have internal rates of return ranging from over 70 percent to less than 10 percent.
Customers may have other investments with superior NPVs that preclude their direct investment, but in an investment climate where it is hard to find yield at various risk levels, there may be other investors whose preferences will make these industrial returns attractive.

One means to overcome an investment constraint is to couple risk and value management opportunities (e.g., from design and operational capitalized expense) with parties seeking alternatives with similar payoffs and durations in the financial markets. Engineers can identify such ideas with tools such as the Digital Twin and performance-based contracts that enable the origination of investment opportunities for others.

**Engineering Skills Involved in Value Creation**

The framework described above explains how engineers can translate the cash flow of customers and their ecosystems into what engineers design, sell, and service in industrial systems markets. Engineering education may not devote much attention to outcomes, performance, risk transfer, optionality, consumption-based operations with financing and integrated performance solutions, but these factors do ultimately affect the demand for engineering skills directly and indirectly.

Modelling skills needed for integrated systems engineering include model-based asset design and control, industrial engineering and operations research simulation and optimization, financial capital structure modelling, industrial risk management, computer science, statistics, signal processing, and data science.

The systems engineer causing new value will consider a customer’s use of assets over an economic lifecycle and optimize design and operations using real option, multi-criteria, and evolutionary approaches to ensure that customer and provider criteria achieve year-over-year performance improvement.
Beyond technical expertise, an engineer must empathize, listen, and persevere to engage the various levels of a customer’s organization as an “outsider” until trust is established. A mix of technical and interpersonal skill development is needed at the intersection of academic courses and mentorship.

The engineering profession, more than any other, can master the expanded portfolio of skills and manage the complex, embedded, and systemic operational/commercial relationship.

**Conclusion**

Consulting organizations have long embraced solutions that integrate technology and process. Complex government procurement contracts have shifted their bias to performance and outcomes. Industrial OEMs, however, engage a limited portion of their offerings in performance- and consumption-based service solutions because the contracts are riskier than traditional transactions and require extended balance sheet management, a lifecycle approach, and an acceptance of various risks (that may not be in their control).

The lifecycle, performance, and consumption-based solution orientation enables a symbiotic forcing function for OEM innovation. It also justifies the requisite investments that more closely address the customer’s actual value creation needs as compared to what is attained with an arm’s-length transactional relationship in which a technology provider is a vendor and value is measured in comparative cost to providers of equipment and/or repair services.

Internal and external business and physical systems can be designed, financed, and operated to create increased economic value and more assured outcomes. Two elements of lifecycle economic value creation are actual increased cash flow (from the use of assets) and probable cash flow (risk management). Engineers can help to both find value that is held back in the business system and maximize assurances that the forecasted productivity will be realized. Engineers in traditional OEMs can make new value in a slow-growth economy by working with customers to identify and move beyond constraints through dynamic systems.

**References**


A better-prepared, adaptable workforce will require a combination of enhanced education at all levels, technology and data, and partnerships between academia and employers.

**Education Transformation to Support Lifelong Learning**

The Role of Public-Private Partnerships and Data

Katharine G. Frase

When most of today’s 8th graders leave school they will work in jobs that do not yet exist. But current education methods and content cannot effectively prepare them, thus creating an employability divide as degree holders emerge into a workplace without the skills that employers need. The nature of work will continue to rapidly change, so both current and future workers will need to constantly update their skills.

It could be argued that people have always needed to be lifelong learners, but that need is now greater than ever. And the need for lifelong learning has implications for every portion of the education and employment pipeline—in fact, perhaps a linear pipeline is no longer the right image for the US educational process.

In this article I explore two foundational issues for lifelong learning. The first challenge is to prepare students to learn how to learn rather than accumulate facts. What changes are required in the curriculum and pedagogy to enable this? The second challenge is to use data on both employer skill needs and individual capabilities and interests to create personalized guidance for learners, whether it is their first or fifth time through education and training.

**Introduction**

In an increasingly competitive global economy, persistent technological innovation is radically changing the nature of work and the skills needed to do that work.
Changes that affect the workforce and training needs can be considered as occurring in three waves. In the first, the existing jobs of the older generation are largely unaffected while the incoming generation learns new things and does new jobs. In the second wave, familiar today, new technologies affect existing jobs as well and many workers feel the need to update their skills to continue to advance their careers. Finally, the third wave, which is rapidly approaching, will compel the next generation of workers to continually update their skills throughout their lifetime as marketplace changes are sustained and actually accelerate.

These changes require a reexamination of education, from curriculum to pedagogy, and the use of technology to create personalized guidance for learners.

**Nurturing Learners with the Right Skills to Succeed**

Besides technical skills or subject-matter expertise, equally important to success in the rapidly evolving workplace are behavioral skills: collaboration, team building, communication, and understanding of the social or cultural context of a type of work.

But according to a recent IBM survey, 51 percent of academic and business leaders believe the current higher education system fails to meet the needs of students, and nearly 60 percent believe it is failing both industry and society (IBM 2015). And a 2012 study by McKinsey reported that 39 percent of employers cite a skill shortage as the primary reason for entry-level vacancies (Mourshed et al. 2012). The employment gap is viewed differently, however, by the three stakeholders—employers, students, and academic institutions: 42 percent of employers and 45 percent of youth surveyed believed that recent graduates were well prepared for the workplace—in contrast to 72 percent of academic institutions that believed their graduates were well prepared (Mourshed et al. 2012; figure 1).

It is clear that employers and educators need to work together to help students (1) develop deep and broad skills aligned to the new economy and (2) become capable of self-learning to ensure their adaptability to evolving workforce needs.

Fortunately, the dual challenges of teaching students not only to be learners, rather than accumulators of facts, but also to have both broad and deep skills are already transforming education at all levels. In higher education curriculum, a number of efforts are under way to produce \(T\)-shaped graduates: the downstroke of the \(T\) represents deep expertise and the crossbar represents broad social and language skills. Innovative approaches are also being developed in K–12 education programs and through partnerships between academia and industry, as described in the following sections.

**Innovation at the College Level**

The challenges to incorporating traditional liberal arts content into technical degree programs are widely discussed (e.g., Bordoloi and Winebrake 2015). Many four-year universities require a structured courseload across
both the student’s major and other disciplines, with the idea that exposure to multidisciplinary content (e.g., through required courses in English, social sciences, and languages that are not part of the major curriculum) will foster the broader skills.

Some programs have moved toward a more project-based, rather than lecture-based, curriculum to improve student engagement and encourage teamwork and communication skills. The incorporation of design in engineering (as at Olin College) or the explicit development of self-reflection and portfolios of experience (as at Dublin City University) support the acquisition of synthesis and self-learning skills within a disciplined framework. Still other institutions are adapting and integrating multidisciplinary content into the core engineering curriculum both to enhance relevance to students’ stated interests and to fit more content into the traditional 4-year degree cycle.

**Besides technical skills or subject-matter expertise, behavioral skills are equally important to success in the rapidly evolving workplace.**

There is a growing corpus of evidence that practical experience for students—for example, through internships and similar approaches—enhances both student engagement and the development of professional skills such as collaboration, communication, and adherence to deadlines and workplace requirements (Craig 2010; Miller 2015). This experimentation with methods and curriculum is vital to discover best practices that can be widely leveraged.

Another approach to open up classroom or external time blocks for discussion, synthesis, problem solving, or practical experience involves the flipped classroom, where traditional lecture content is consumed online before class. The transformation of the traditional lecture format has a number of benefits and challenges. Creating compelling online content requires more than simply posting the same lecture that has been used for many years: new modalities (video, simulation, gaming, collaboration) and in-line formative assessments are needed to ensure that students digest, rather than skim, the content. The role of the faculty shifts from “the sage on the stage” to coaching, facilitating, and mentoring, and assumes a level of comfort with using technology in these ways. Significant professional development and willingness to experiment are needed.

The flipped classroom model can deliver benefits beyond time management. Students who explore multimodal curricular materials are more likely to develop self-learning skills. Moreover, the digitization of educational content (including reference, instructional, and student-generated material) inherent in the flipped model enables the collection of near-real-time data to assess the understanding of concepts by an individual student or a class group, providing insights to the instructor on which topics to emphasize in the classroom. The data can also be mined to assess student performance risk and to create personalized recommendations for additional content (whether for remediation or advanced learning). The digital format thus allows the entire class to move forward, but on individualized paths of content and time.

At Marist College the Open Academic Analytics Initiative\(^1\) created a risk-alert system using predictive analytics to identify and warn students that their trajectory may not lead to success in a specific course, allowing professors and students to take timely action early in the course. Similar programs at Purdue and other universities have demonstrated the power of data when coupled with analytics in support of decision making (Pistilli et al. 2012).

**Innovation at the Precollege Level**

Not every worker will, or should, be the product of a 4-year college education, so incorporating “T-shapedness” in K–14 and vocational education systems is critical.

In the United States (and elsewhere), however, K–12 education is increasingly defined by standardization of the facts or functions that students are expected to have mastered at each level. Educators need to ensure that students are also gaining the skills they need for lifelong learning, multidisciplinary insight, and employment.

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\(^1\) Information about the program is available at https://confluence.sakaiproject.org/pages/viewpage.action?pageId=75671025.
IBM and others are beginning to pilot solutions in these areas, demonstrating the value created for students, their family, their community, and local businesses. For example, in the Gwinnett County (GA) public schools, teachers are being supported with insights about their students and effective intervention methods that go beyond academic methods. Under the leadership of long-standing superintendent J. Alvin Wilbanks, the schools have invested in technology to increase student engagement, develop the professional skills of faculty and staff, and enable teachers to better understand and intervene with individual students within the constraints of curricular standards and time pressures.²

**Innovation Through Public-Private Partnerships**

A recent study by the Conference Board (2015) underscores the importance of public-private partnerships and of policy decisions at the employer, government, and education institution levels to improve both the alignment of coursework to workplace needs and the use of these educational pathways. New and innovative educational models are taking shape.

One prominent example is Pathways in Technology Early College High School (P-TECH), which began in Brooklyn in 2011, is spreading to nearly 40 schools around the nation, and is projected to grow by 2016 to an estimated 100 schools both in the United States and in some foreign countries as well (Fritz 2014). P-TECH’s six-year program, with a variety of corporate partners and targeted curricula, combines academic rigor with career focus: students are paired with mentors from the business community and gain practical workplace experience with paid internships. After earning a high school diploma and a no-cost, industry-recognized associate’s degree, graduates are first in line for jobs with an employer partner.

P-TECH’s innovative education model is designed to build 21st century skills, fill in-demand jobs in the United States, and ensure that young people are college and career ready in the skills of science, technology, engineering, and math (STEM)—disciplines that underpin some of the country’s fastest-growing industries. Other similar models are being developed, such as the Georgia Career Pathways Initiative, in which employers “adopt” a career pathway and work with the Georgia State Department of Education to build a K–14 curriculum, including internships and mentoring.³

Partnerships between business and academia can also help craft new curricula and sponsor practical experience for students at the college and university level. A few years ago experts began to predict that data analysis skills would need to be improved to meet marketplace needs as businesses move toward more automation and faster decision-making cycles (Manyika et al. 2011). In response, IBM and several other companies worked with universities to establish the Big Data University (www.bigdatauniversity.com), which creates curricular content, case studies, and new degree programs in the United States and overseas and allows users (now over 250,000 registered) to learn data science technologies. The goal is both to prepare students with the skills they’ll need to work with big data and analytics and to fill the skills gap for companies across industries from health care to finance to manufacturing.

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³ Information about the initiative is available at https://www.gadoe.org/Curriculum-Instruction-and-Assessment/CTAE/Pages/Georgia-Career-Pathways-New-Rule.aspx.
issue. And academic institutions are often unaware of new workforce needs, or are slow or unable to change their curriculum or career counselling.

The use of data and analytics to inform decision making can help, especially in the guidance counsellor’s office. Many high school and college counsellors handle hundreds and in some cases a thousand or more students, with little information besides a transcript and a five-minute interview with the student about her interests. Yet in many cases data exist and can be used to better guide such conversations in the following ways.

- A student-centric approach to data can create a holistic view of each student, including detailed analysis of academic strengths and weaknesses, extracurricular interests, and other factors.

- A composite view of the pathway for, and characteristics of, different careers (e.g., number of years in school, kinds of courses, book vs. hands-on learning, earning potential, geographic location) can help students begin to understand which careers might fit them and can enrich and focus the counsellor’s discussion more meaningfully.

- Inclusion of skill requirements in the strategic planning of local employers can help them predict what skills they really need. What are the characteristics of their most successful employees? (The answer to this is often not as simple as what courses they took or what degree they received.) Will those skills likely be the same or different in 2–3 years? If a company is planning to expand its product line or retrofit its factories, how will that affect the skills needed, not just the number of employees?

These three elements—insights about the individual student, the career pathway, and employer needs—can together support progress toward better employment outcomes for all concerned, and can be similarly used for adults who want, or need, to change careers.

**Conclusion**

Education has always been vital to economic success at the individual, community, and national levels, but has often struggled to respond in a timely manner to changes in the economy and the workforce. The need for timely adaptation is now acutely important in the rapidly evolving national and global economy. Efforts to improve success across the employability divide call for a combination of enhanced education at all levels, technology (particularly data-driven insights as education becomes more digital and instrumented), and public-private partnerships between academia and employers.

**References**


A system is needed—with structure, guidance mechanisms, and adaptability—to support lifelong skill development at all levels.

One day she learned something and the next day was left to do it alone. . . . Out here she saw it all the time, . . . nurses and soldiers and doctors and drivers and engineers alike, no one did what they’d been trained to do, they did what needed doing. She learned more in six weeks than she had in six months of concerted practice at home.

– Barrett (2013, p. 210)

A century ago, the majority of young people left US schools after seven or eight years, having learned enough, in the eyes of most, to exercise the rights of citizenship and earn an acceptable living. Subsequent decades brought world wars, the 1930s depression, and a great deal of technological and economic change. During three decades or so following World War II robust productivity growth fed steady increases in wages and benefits—a period my coauthors and I called the Wonder Years (Herzenberg et al. 1998). It did not last. Since the 1970s pay has stagnated for many millions of workers, with widening gaps between those in the topmost tiers of the distribution—mostly white male college graduates—and the rest (figure 1).

Debate about the causes has focused mostly on education and in so doing misses at least half of the problem and the possible solution set. In some accounts it can seem as if an individual’s working life is determined at the point of school-leaving, her prospects and earnings following a ballistic trajectory (with leaving college short of a degree amounting to something like failure to launch). In fact, many of the actual skills used in actual workplaces
are only loosely connected with formal education, and the many ways in which people learn outside of school get far too little attention.

There are two main reasons why formal education gets so much attention and informal learning so little. First, many skills are hard to measure or even to observe, so that employers hire in large part based on educational credentials: in the absence of better indicators, education serves as a signal. Second, as Peter Capelli (2014) has argued, even as employers complain that workers lack needed skills, they have pulled back from support for education and training, pushing more of the costs onto schools and society at large. In so doing, businesses have left educational institutions—secondary schools, community colleges, universities—no real choice but to try to prepare young people not just to enter the labor market but to enter with employer-ready skills.

It is wrong to expect schools to produce “job-ready” workers. Indeed, attempts to do so aggravate the underlying problem, which is one of adaptation to the always unknowable future. No one can know what sort of skills young people in school today might need 30 or 50 years from now. New systems—new institutional structures—are needed, designed to support ongoing learning for everyone.

**Trends**

There is no debating the evidence of wage stagnation and wage dispersion, only the causes. During the 1970s productivity growth slowed and, as figure 1 shows, wage growth for those in the lower tiers of the distribution stopped. Benefits also declined (CEA 2015, pp. 149–151).

Some observers pointed to the productivity slowdown itself, arguably associated with lagging innovation, as a cause. Others blamed globalization and imports from low-wage countries. Neither explanation persuades: there are too many confounding variables and too much left out of account. For example, also beginning in the 1970s a growing fraction of the rewards from increasing productivity flowed to capital (e.g., business profits) (Fleck et al. 2011). For decades, compensation—wages plus benefits—had risen in lockstep with productivity, the labor share of output remaining roughly constant at around 70 percent. The labor share has now fallen to about 60 percent, a decline that would appear still more dramatic if the compensation of earners at the very top (say, the 99th percentile) were left aside.

There is more to understand than the widening gaps between deciles. Economists analyze such trends in terms of human capital—the knowledge, skills, and competencies that employees bring to the workplace. Unlike physical capital—blast furnaces, computer systems, and so on—human capital cannot be measured directly, only inferred. Census data on educational attainment—years of schooling—have been the usual proxy, sometimes supplemented by years of experience. Here too things have changed, as figure 2 shows, with widening gaps in pay separating those with more schooling from those with less—another shift that demands explanation, and one that underlies much of the attention focused recently on education.

The retreat of business firms from efforts to enhance the human capital on which their own operations depend—through apprenticeships, internal labor markets providing training and well-marked career ladders, and workforce preparation more generally—is more difficult to document quantitatively. But it is...
consistent with other evidence of growing separation between the interests of capital and those of society as a whole, such as the much criticized tendency of businesses to underinvest for the long term in favor of immediate profits.

**Explanations**

Partial explanations for the patterns shown in figures 1 and 2 abound. The manufacturing share of US employment peaked in the mid-1950s at nearly 30 percent. A source of stable, well-paying positions for those with a high school education or less, unionized industries such as steel and automobiles provided pathways to the middle class and collective bargaining agreements pushed up wages elsewhere in the economy (Western and Rosenfeld 2011). But manufacturing employment now stands at just over 11 percent, and union coverage has declined in all sectors.

**Declining Wages and Benefits**

With high wages taking part of the blame for the competitive difficulties of US manufacturing, employers resurrected earlier antiunion strategies such as “right to work” laws (Griffin et al. 1986). Textile and apparel firms had already moved from New England southward. From the 1960s on, the steel industry restructured on the basis of nonunion minimills, many of them also in the South. When foreign-owned automakers began to invest in the United States they, too, often chose border and southern states. Two-tier wage structures now leave many people in auto and auto parts plants doing the same work for less pay and fewer benefits (Welch 2015).

Long common in service industries, contingent employment, a term that covers both part-time and temporary employees with no expectation of a permanent job, has now spread to manufacturing (Dey et al. 2012). Contingent workers usually earn less on an hourly basis than those with “regular” jobs in the same firm; they also lose out on benefits such as cost-shared retirement and health insurance plans, even sick days. Although some people prefer to work part time, for others it is the only job they can get. While daily and seasonal sales fluctuations in industries such as retailing help justify part-time and temporary arrangements, a growing number of employers have come to view contingent workers simply as another way to hold down costs (Stone 2015).

With freelance work expanding, facilitated by digital ubiquity, it may soon be appropriate to think in terms not just of contingent employment but of irregular employment. To the extent that growing numbers of Americans sell specialized skills, abilities, and assets over the Internet and in some sort of “sharing economy,” this type of work, while it may benefit many people, could also come to seem a high-technology version of the casual employment associated with poor countries, leaving behind those unable to carve out a secure niche.

**Human Capital**

Figures 1 and 2 cover all US employment—nearly 160 million people working in jobs the Labor Department classifies into some 1100 occupations. The labor market is big, and the dynamics messy. Economists, perhaps needless to say, approach these dynamics in terms of supply and demand: When pay rises disproportionately in the upper tiers of the wage distribution and for workers with more education (i.e., more human capital), this must reflect in some way a rise in demand relative to supply.
But what is the cause of this rise? Early explanations cited technical change, notably the spread of digital systems (see, e.g., Bresnahan et al. 2002). Auto mechanics, after all, now diagnose faults in microprocessor-controlled powertrains, Wall Street traders make their millions with the help of algorithms developed by PhDs, and farmers will soon rely on drones to monitor crops. The so-called knowledge economy seemed to raise wage premia for workers able to learn and adapt, and many analysts went on to assume that education could serve as a proxy for these abilities.

Recent studies go somewhat beyond simple human capital models based on educational attainment. The OECD’s Programme for the International Assessment of Adult Competencies (PIAAC), notably, assesses literacy, numeracy, and computer-based problem solving (Paccagnella 2015; also see Autor and Handel 2013). Yet these too are crude measures; job skills and ability are hard even to observe. Who can tell whether their child’s fourth grade teacher, or a local auto mechanic, or the family physician is above or below average? Any careful look at workplace practices—whether those of warehouse employees who plan in their heads the shortest routes through labyrinthine settings or the vastly different skills of creative engineers and scientists—will show the differences between what people learn in school and what they do in their jobs (Alic 2008).

Any careful look at workplace practices will show the differences between what people learn in school and what they do in their jobs.

At the same time, it seems plain that wages rise for workers with more years of schooling not so much because the jobs they fill require particular skills (excepting more specialized occupations such as nursing or engineering or professional sports) but because employers act as if educational attainment signals potential (Spence 2002). Employers, in other words, weigh job candidates on the assumption (perhaps implicit) that those with more education will be safer bets, likely to have “basic employability skills (attendance, timeliness, etc.) and the ability to work well in a team environment” (Deloitte and the Manufacturing Institute 2015, p. 6). Another survey states, quite bluntly, “employers have frequently come to rely on a bachelor’s degree as an employment screen, even if it may not be related to actual job duties” (Accenture et al. 2014, p. 18). The signaling function of educational credentials extends from low-wage jobs in, say, the front offices of retail banks to highly coveted positions in prestigious law firms, investment banks, and consulting firms (Rivera 2012).

Technological Change, Deregulation, and Globalization

A look at three broad forces affecting earnings—technological change, deregulation, and globalization—gives further insight into the trends illustrated in figures 1 and 2. Taken together, these forces spur economic dynamism, boosting productivity and creating much new wealth and many new jobs as businesses expand and hire more people. At the same time, less efficient older firms, if unable to adapt, decline and some die off.

The direct impacts of technological change on workers have probably been greatest in offices. During the first half of the 20th century US high school enrollments exploded in response to demand for clerks, typists, bookkeepers, secretaries, and administrative employees. Some of these jobs began to vanish in the 1960s as stand-alone computing systems took over tasks once performed by millions of modestly educated office workers (Alic 2004)—with more displacement to come, as suggested by rapid advances in powerful computing systems implementing forms of artificial intelligence and apps for everything.

Technological change also forced deregulation of industries such as telecommunications, and helped open the way for competition from low-wage countries, not just in goods-producing industries such as steel, electronics, and automobiles but in many services as well. With low-cost international voice and data transmission, call center personnel in the Philippines or India could compete with those in Des Moines or Sioux Falls, and some better-paid work such as software coding and radiological interpretation has also migrated overseas, again with more to follow.

While the ramifications of technological change include job creation associated with expanding industries such as mobile telephony, other opportunities
have disappeared. Before deregulation and the waves of disruptive innovation that have swept through the economy, an entry-level position might open the way to career progression along well-marked job ladders in the internal labor market of a bank, downtown department store, or telephone company, with on-the-job learning and advancement leading to a position as loan officer, buyer, or maintenance supervisor. Few such career paths remain and more people must acquire new skills on their own, outside the workplace.

Whose Interests?

In one way or another, all wealthy countries seek a balance of some sort between the positives and negatives of Schumpeterian creative destruction. In this respect, as in many others, the United States stands out as exceptional, arriving at what can only be termed an imbalance, with labor market policies that cater unabashedly to employer interests at the expense of employees (Estlund 2002; Robertson 1988).

Each year tens of millions of Americans enter or exit the workforce or move from one job to another; in 2014 employers hired some 59 million Americans, about 3 million more than the number who quit a job or were laid off or fired (BLS 2015). Labor market churn both drives competition and innovation and is a consequence of these forces. Engineers, scientists, and managers leave their jobs and take their know-how and ideas to other companies or perhaps start their own. Other workers, though, are threatened. People with unimpressive educational credentials may have an abundance of skills that employers seek but no good way to signal them. For similar reasons, experienced and productive employees with generic skills and less education may be laid off first when organizations downsize, and if they can find a new job will likely earn less than before (Couch and Placzek 2010).

Neither public nor private sectors in the United States invest much in active labor market measures such as training and job placement assistance to help people prepare for new work (as opposed to passive measures such as unemployment insurance) (Martin 2000; Nie and Struby 2011). With some exceptions for fast-tracked technical and managerial employees, employers do relatively little to train their workers. Only about 20 percent of employees surveyed by Accenture (2011), more than half of them with four-year or graduate degrees, reported gaining skills through employer-provided training over the five-year period 2006–2011. Other studies find that both on-the-job and employer-sponsored off-the-job training have declined since the mid-1990s (e.g., CEA 2015, p. 147).

Remedies

Limits of Formal Education

The near universal prescription for the problems summarized above has become more and better education for all. A simple thought experiment suggests the fallacy. Suppose that everyone in the labor force had a four-year college degree. What, exactly, would change? Would employers raise wages? Alter their hiring and promotion practices? Not likely. They would still respond to educational credentials as a signal. Overeducation and underemployment, already common, would rise. The economy might adjust to take advantage of a workforce with higher average levels of education, but no one can say what this might mean for wages.

Suppose that everyone in the labor force had a four-year college degree. What, exactly, would change?

The starting point in seeking remedies is to accept that formal education is no panacea. All learning is in some sense experiential, something everybody at some level understands (think about how much children learn before they enter kindergarten).

Beyond basic skills—reading, writing, arithmetic—and some capacity to learn, employers place considerable value, nearly regardless of the position, on ability to work with others, communicate effectively, accept authority, and follow directions. Some jobs, of course, demand specialized skills. As Google chairman Eric Schmidt put it, “You cannot innovate and build new products without engineers in your field” (quoted in Huey et al. 2013, p. 80). Firms in such industries, well aware that a handful of highly creative individuals or even a single extraordinary “talent” can create a billion-dollar revenue stream, arguably seek a larger STEM (science, technology, engineering, and mathematics) pipeline to maximize the chances of finding superstars (Lev-Ram 2015).
Yet it should be clear that correlations between what people learn in school and actual skills used in actual workplaces can be elusive, even for occupations such as engineering. Anyone who has earned an undergraduate degree and then taken an entry-level engineering job will recall, as I do, how much there was to learn in the first few weeks and months—and in all the years that followed.

Even in the 21st century, for example, large numbers of people find their way into STEM occupations without academic credentials in STEM fields. Recent US Census surveys continue to show that many Americans working in occupations classed as science and engineering hold degrees in non-STEM fields and about one quarter of workers in these occupations have no four-year degree at all (NSB 2014, p. 3-15).

Entry into engineering and related technical fields has always been a source of strength for the US economy, the world’s most innovative. More than twice as many Americans have found jobs associated with computer and information technology than have graduated from four-year programs since colleges and universities first began to offer computer-related coursework in the 1960s (Alic 2010). They learned in the workplace, from their own experience and that of their colleagues; from handbooks, manuals, and other codified literature; from formal and informal instruction provided by employers, hardware and software vendors, consultants, and trade and professional societies; and from short courses offered by colleges and universities. This sort of learning is essential and indeed inevitable; it should be encouraged and supported.

New Approaches to Skill Acquisition
A good deal is known, in part based on advances in cognitive science and related disciplines, about how people develop competence and expertise and about how the sort of learning that takes place after people have left school could be enhanced (see, e.g., Bransford et al. 2000). As yet, little of this has found its way into the larger debate.

A dozen years ago when I argued for new approaches to skill acquisition, a common response was something like, “Well, the Internet will take care of it.” Now I think people recognize the pitfalls that come with easy access to huge amounts of undigested information, some of it wrong or contradictory or simply of unknown reliability. Improvements have been coming, albeit in pieces—MOOCs (massive open online courses), online encyclopedias and handbooks that can be updated constantly, technology-focused chat rooms (e.g., for trading work-related problem-solving lessons), and ventures into personalized, computer-based learning.

These and other new means of facilitating skill acquisition coexist with the heterogeneous offerings of colleges and universities, trade associations, and professional societies directed at those already in the workforce. So far, little is known about the effectiveness of such offerings, with the exception of continuing medical education, which has been extensively evaluated because it is a common (and costly) requirement for board certification. The evaluations have shown it to be almost totally ineffective in changing what physicians do in everyday practice (Grimshaw et al. 2001) (perhaps because, unlike a number of other high-skill occupations, weak market forces—namely the inability of typical patients to judge physician competence—reduce incentives for learning once medical school has been left behind). As this example suggests, experimentation and evaluation will be necessary to fill the vacuum that now exists between formal education and unmediated experiential learning, which, again as most people at some level understand, tends to be painfully slow and error-prone.

On a societywide basis, flexible institutional structures should be designed for everyone, not just those who are motivated and capable of self-directed study—they should support, in effect, “just in time” learning. Without more structure and guidance too many people will flounder—a recipe for still more inequality. Feedback and adaptability—self-management and self-correction—should be watchwords.

Conclusion
The personal experiences of many Bridge readers can serve as representations of a major task that American
institutions concerned with education and training face as the 21st century unfolds: learning, in all its facets, to deal more effectively with a radically uncertain future. Adaptation has lagged because the steamroller force of post–World War II technological and structural changes has been apparent mostly in hindsight. Social learning will be essential and many of the lessons of the past will have to be modified or discarded.

In this light, the nation’s institutions for continuing education and training can only be seen as inadequate and anachronistic. The current nonsystem leaves the burden of managing learning—navigating through a vast maze of possible opportunities and potential cul-de-sacs—to individuals. Once they leave school, support structures fall away, and so, for many, do prospects for satisfying careers.

Responses to current and future skill gaps require greater attention to learning that takes place outside of school and after labor force entry. Networks to provide such learning will have to address the varying needs of an expanding labor force that already numbers nearly 160 million people. Demand for skills will change over time, perhaps quite dramatically—as illustrated by the past half-century of digitization. Flexibility will be essential, with multiple delivery modes that are at once tailored to individual learning styles and skill sets and designed to exploit advances in cognitive science and artificial intelligence. Incentives will have to be put in place to encourage both employees and employers to participate.

Whatever directions this evolving learning structure or system takes, it cannot be defined by what employers want. Beyond the simple truth that employers’ interests do not align with those of individuals or society at large, businesses (and most other employers) emphasize today’s jobs, knowledge, and skills, not tomorrow’s. Employers should have a voice, just not a determining one.

References


A modern-day revolution in manufacturing prioritizes social inclusion, education and workforce development, community development, and environmental restoration through public-private partnerships.

Balancing Innovation in Technology with Social Inclusion
The Second Industrial Revolution

News stories describe the marvels of a hand-held device with more power than the Apollo space rocket, apps that can do almost anything, a driverless car being tested on city streets, 3D printing that creates a low-cost functional prosthetic hand, robots that perform advanced surgery, and projects that push the limits of artificial intelligence.

These new technologies suggest that a truly advanced society is achievable, and they may even give rise to utopian dreams.

Yet other stories in the media on any given day suggest that dystopia could prevail:

- Income inequality is increasing: 80 people have the combined wealth of half of the world’s population.
- In the United States there are troubling signs of deepening racial polarization, with the killings and demonstrations in Ferguson, Staten Island, Baltimore, and Cleveland.
- An environmental crisis threatens daily life in very immediate ways in every section of the country, from Beverly Hills to Staten Island to New Orleans.
- Many major cities are actually two cities with the same name in the same location, one populated by those who are white and wealthy and the other by people of color who are poor.

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• Increasing political polarization at every level of government hampers responses to conditions that require a unified and effective effort.

These serious concerns share a significant contributing factor: manufacturing, as shaped by the First Industrial Revolution. After sketching the history and impacts of the First Industrial Revolution, I point out the long-term costs of its values—all too evident today—to the US economy, society, environment, and manufacturing sector. Those values were principally the private accumulation of wealth. At this last stage of the First Revolution, that priority has deeply compromised the health of the US manufacturing sector and society.

Yet even at the birth of the First Industrial Revolution, there were the seeds of a Second Industrial Revolution—a revolution led by the public sector with a vision of manufacturing as the essential means to solve fundamental social, economic, and environmental problems. This “revolution” prizes a modern education system, community engagement, and environmental sustainability and restoration through public-private partnerships. These partnerships recognize the absolute necessity of a strong financial return on investment for the private sector partners.

In this article I present three regional examples of a modern-day Second Industrial Revolution that can lead the United States toward a brighter, stronger, and more prosperous future.

The First Industrial Revolution and Its Long-Term Impacts

The First Industrial Revolution, beginning in the late 1700s and first formed in cities such as Manchester, England, was motivated by a new private sector freeing itself of the shackles of feudal rule. The pioneers of industrial production launched a wave of development that resulted in an explosion of innovation in technology, in the character of production, and in wealth creation—and gave rise to the modern world.

But industrial development was principally driven by a desire for private accumulation of wealth by the leading entrepreneurs and financiers, and from the beginning there were intended as well as unintended negative consequences. Grueling child labor, long days, low pay, and dangerous working conditions became commonplace. Cities were stratified into rich and poor neighborhoods. And later the contamination of the environment became evident, much of it from unregulated or unsupervised production practices and processes.

Although some governmental systems emerged or adapted to address the changing economic and social landscape, the private leadership of production remained essentially unchanged. It yielded steady progress—particularly in the developed world—and so made the costs acceptable. In the United States, the dramatic growth of production created a prosperity and a broad-based stable middle class that became the envy of the world until the early 1970s.

US Industry and Manufacturing: Financial and Technological Impacts

In the early days the development and maintenance of the industrial base relied on patient capital. In the 1970s new information technologies emerged as did the modern computer. These breakthroughs not only began to revolutionize production but gave the financial community the ability, through the skillful use of new tools and products, to gather and analyze trillions of bits of information in microseconds—and with it the ability to shift capital around the world and make enormous wealth. Such wealth was often made by cannibalizing the same manufacturing companies that had been the beneficiary of investment for decades.

New technologies and capacities also allowed large companies to quickly move production offshore in the search for lower-cost labor. David Roderick, former CEO of US Steel, is reported to have said “I’m in this business to make money, not steel.” Manufacturing became deeply impacted by short-term thinking that focused on the highest financial returns in the shortest amount of time.

With these developments the character of US manufacturing began to fundamentally change in the late 1970s, when jobs were lost and factories closed.
senting one third of the workforce. From 2000 to 2009, over 60,000 factories closed, including 40 percent of the country’s largest factories that each employed over 1,000 people (Miller 2014, p. 10).

In the mid-1980s there arose a number of disputes around the country between labor and management, manufacturers, cities, and communities about plant closings. By the late 1990s low-skilled work in the United States had, in large part, moved offshore and what is now called the skills gap became apparent.

A powerful section of the private sector had walked away from serving as the steward of productive capacity, and with the decline in manufacturing came the acceleration of social problems such as poverty. At the same time, public education was subjected to massive cutbacks in vocational education programs, stripping the connection between education and the manufacturing sector. This loss was exacerbated as the latter embraced new technologies that required more skills for even entry-level workers because companies found that if they wanted to survive they had to shift to high-value-added work—to advanced manufacturing and technological innovation.

But with this shift American manufacturing companies discovered that they couldn’t find the talent they needed for production—a problem that is becoming particularly acute with the retirement of baby boomers. The numbers were significant. In Chicago in 2001, some 10,500 jobs in manufacturing had to be filled, whereas there were, at best, only 5,600 qualified candidates for those positions (CFL and CLCR 2001, p. 88). At the same time, there were thousands of people, many in innercity communities that had been devastated by deindustrialization, desperate for jobs and careers.

What does the future hold for the US manufacturing sector and society?

The Early Seeds of the Second Industrial Revolution

Even at the time of the First Industrial Revolution, some pioneers had a different vision of how industrial capacity could be developed in ways that supported greater public involvement, innovation, and productivity for broader benefit. These were the early seeds of the Second Industrial Revolution, embedded in the same soil as the First.

In 1817 Scottish industrialist Robert Owen called for his cotton mills to be guided by the principles of “eight hours labor, eight hours recreation, eight hours rest” (Widrich 2014). By the 1840s, just outside Manchester, England, cooperative enterprises had formed under the umbrella of the Rochdale Cooperatives1 and were managed democratically.

Since the 1940s another trend in manufacturing has evolved, led by visionaries driven by a desire to innovate in both manufacturing and community development. They saw manufacturing as a means to reduce poverty and build a broad-based middle class. As the world acknowledges and contends with the social and environmental impacts of the First Industrial Revolution, manufacturing can be a means to address them through new products and processes. This idea is vividly exemplified by two regional economies—Mondragón in Spain and Emilia-Romagna in Italy—that are global leaders in advanced manufacturing and that became the inspiration for an effort to rediscover, redefine, and rebuild manufacturing in an innercity Chicago community.

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1 The Rochdale Cooperatives, established in a village of the same name in the mid-19th century, were based on principles such as democratic management, economic participation, education and training, and concern for community. They were the basis for the creation of the International Cooperative Alliance (ica.coop).
Obrázki started a small polytechnical school in the 1940s with 20 students. They studied various technical components of manufacturing as well as Arizmendi’s strong social values. In the 1950s five of the students purchased a small gas stove company, which they organized as a cooperative: one worker/one vote, and the highest paid didn’t make more than 3 times the lowest paid. This formula for management and compensation permitted significant reinvestment of the margins, to promote both technical and workforce innovation. Despite fears to the contrary, the company was very successful.

**One formula for management and compensation permits significant reinvestment of the margins to promote both technical and workforce innovation.**

Today, the Mondragon Cooperative Corporation (MCC) comprises more than 250 companies, employing about 83,000 people and representing diverse businesses from manufacturing to banks and supermarkets. In 2011, the company had 94 overseas plants, including 13 in China, and $4.41 billion of the $6.59 billion sales in its industry division were outside Spain.

In 2013 the MCC won the prestigious ArcelorMittal Boldness in Business Award for “lo que representa en términos de una nueva propuesta real de modelo de negocio, ‘Humanity at work,’ basada en la cooperación, en el trabajo colectivo, en la solidaridad, y en la implicación de las personas en el ámbito laboral” (Europa Press 2013).² The Financial Times, a sponsor of the prize, noted that the corporation “remains profitable while paying 90 percent of its workers more than their peers at rival companies” (Johnson 2013).

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² Translation: “for what it represents in terms of a real proposal of new business model, ‘Humanity at work,’ based on cooperation, collective work, solidarity, and the involvement of people in the workplace.”

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**Emilia-Romagna: Political Leadership**

Emilia-Romagna (ER) is a region in Northern Italy that includes Bologna, its capital. Known for major auto companies such as Ferrari, Lamborghini, Maserati, and Ducati, it features a high standard of living, great food, and beautiful small towns. It also has more entrepreneurs per capita than any place on earth, as well as numerous small manufacturing companies, many cooperatives, and a unique history of state and political forces shaping the region based on more community-based values and performance.

ER was a backward and undeveloped region of Italy before World War II. Under Mussolini, the Italian Communist Party led the partisan guerrilla war to defeat the fascists. It also distinguished itself from the international communist movement by embracing market economics, democracy, and entrepreneurship; supporting the development of cooperative firms; and recognizing the importance of building the manufacturing sector through the development of small firms.

ER benefitted from these approaches and is now one of the wealthiest and most developed regions in Europe, with the third highest GDP per capita in Italy. It has 60,000 small companies—many in advanced manufacturing—an indicator of the entrepreneurial culture. For example, the small town of Ozzano dell’emilia, with a population of just 11,400, has 1,400 businesses (Pfleger 2012).

Cooperatives—businesses owned and managed by their employees, consumers, clients, or suppliers—are also integral to the ER economic success. The town of Imola is fairly typical: 50 percent of its residents are members of a cooperative and 17 percent of the workforce is employed directly by cooperatives (Hancock 2007).

Complementing the strength of the cooperative movement and large number of small, privately owned companies, the region’s government is instrumental in promoting the competitiveness and development of its manufacturing sector. Since World War II the regional and local governments in ER have played a very active role in promoting innovation and competitiveness, particularly through small and medium-sized enterprises.

Leading this work over the past 35 years has been the regional consortium for innovation and technology transfer ASTER (www.aster.it), formed in 1980 to implement the region’s policies to promote innovation. ASTER has organized service centers for clusters of small companies in a particular sector to increase their com-
petitiveness globally—a practice that has now evolved to creating strong linkages between universities, research centers, and small companies. Today this small region has 89 industrial research centers and enables almost 600 graduating engineers to work in small companies for three years at no cost to the company.\(^3\)

ER represents key values of the modern-day revolution in industrial development in its promotion of advanced manufacturing tied to innovation and community and workforce development, reflected in its extensive cooperatives and the active engagement of the public sector.

**Chicago: Public-Private Partnerships with Labor in the Lead**

During the labor disputes of the 1980s Chicago saw bitter and polarizing fights at Brach Candy Company, Stewart Warner, Playskool, and a number of other major manufacturers. Inspired in part by examples such as Mondragón and Emilia-Romagna, Chicago's Federation of Labor (CFL) partnered with the Manufacturing Renaissance (MR; a not-for-profit consulting and research company focused on the challenges of manufacturing) to address the emerging crisis. They had come to understand that the loss of manufacturing was not inevitable or beyond remedy; that manufacturing was essential for a sustainable and secure workforce and society; and that both the public and private sectors could intervene in a way that addressed the needs of both the private sector and society.

The CFL and MR secured a grant from the US Department of Labor to study the increasingly evident failure of the public education system to meet the needs of the manufacturing sector and of residents eager for employment. The study not only documented the problem but proposed practical reforms based on best European practice in education linked to manufacturing (CFL and CLCR 2001). The analysis and recommended reforms caught the attention of the manufacturing sector and some of its associations and led to a new partnership, the Chicago Manufacturing Renaissance Council (CMRC), committed both to advanced manufacturing as a foundation for the region and to development in the communities devastated by deindustrialization.

This fusion of the promotion of advanced manufacturing and technological innovation with workforce and community development lies at the heart of the mission of the revolution in the development of the manufacturing sector. In Chicago this was led, in large part, by the labor movement rather than the private sector in manufacturing.

The first and most widely known project of the CMRC was the creation in 2007 of a public school in the inner city, the Austin Polytechnical Academy (APA), and a Manufacturing Connect\(^4\) program linking the school to the manufacturing sector—an excellent example of the programs and partnerships representing the new revolution. Austin was one of the most challenged communities in Chicago, with high rates of poverty, unemployment, crime, and a low-performing public school system. The location was chosen to demonstrate CMRC’s commitment to advanced manufacturing and community development.

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**Austin Polytechnical Academy educates the next generation in all aspects of manufacturing—not only production but also management and ownership.**

Rather than a traditional vocational school, APA was modeled after the founding school in Mondragón, to educate the next generation of leadership in all aspects of manufacturing, including not only production but also management and ownership. It’s one of three small schools housed in the Austin campus and has about 130 students. Fifty-five companies partner with the academy, principally out of self-interest in finding the talent they need to compete in the global economy. The school’s WaterSaver Faucet Manufacturing Technology Center is accredited by the National Institute for Metalworking

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\(^3\) Paolo Bonaretti, managing director of ASTER, Emilia-Romagna Region and ASTER presentation, April 14, 2014.

\(^4\) Manufacturing Connect is a program of Manufacturing Renaissance creating a partnership between Chicago Public Schools, local manufacturers, and the Austin community that provides students with college and career exposure, field trips to manufacturing companies and trade shows, job shadowing experiences, paid internships, summer jobs, industry-recognized machining credentials, and full and part-time employment after graduation.
Skills (NIMS) and, in addition to a high school diploma, students can secure nationally recognized portable NIMS credentials in metalworking and college credits. Manufacturing Connect is recognized, after initial skepticism, as an essential program for redeveloping the community. Leaders in other states are looking to it as a model for promoting advanced manufacturing to develop challenged communities, and the program received a $2.7 million grant from the US Department of Labor in recognition of its potential for replication in other cities.

**Conclusion**

America is a society of increasing contrasts. The improvements that accompany constant technological innovation are offset by growing income inequality, marginalization of many communities, a shredding of the social safety net, and growing political polarization.

The health, management, and development of the US manufacturing sector are critical in determining whether utopia or dystopia is in America’s future. The dynamic examples described here, of a modern-day second revolution in industrial development, herald new possibilities in which investment in technological innovation is matched by investment in solving social, economic, and environmental challenges. This new movement, led by a broad coalition of public and private sector leaders, suggests an optimistic future.

**References**


MOOCs have the potential to expand access to student learning at all levels if . . . .

On MOOCs

Louis L. Bucciarelli and David E. Drew

In the past few years leading, world-class universities have initiated massive online open courses (MOOCs) with the goal of providing high-quality educational experiences, free, to people around the world. Now a variety of institutions offer such courses, some for free, some for a fee.

MOOCs may reshape higher education. Or they may not last long in their present form.

Introduction

MOOCs have provoked new thinking about strengths and weaknesses in traditional undergraduate education as well as how best to take advantage of the technology of online learning.

At this stage, it is not at all clear how the ideas, methods, and structure of MOOCs might be deployed and used to advantage by teachers and students. Some see an opportunity to significantly cut the costs of postsecondary education as, in an ideal form, a MOOC has little need for staffing once the video lectures, readings, and exercises have been posted online.

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1 We use “teacher” to refer to professors and scholars for students at all levels.
We focus on the MOOC as a phenomenon of online learning that is unique in several ways: First, the courses are offered free of charge, for now at least and for the most part. Second, they are built on existing courses at a variety of colleges and universities and designed for undergraduates at these institutions.

The online courses are produced and made available through independent providers (e.g., Coursera and edX) that operate an online platform for access to and enrollment in the courses. They serve as a clearinghouse for MOOCs offered by universities all over the country and indeed the world, from Johns Hopkins to Peking University, the University of Edinburgh to the University of Michigan.

Claims

Providers trumpet a new approach to education, claiming the MOOC dramatically expands access to high-quality instruction for study and professional growth. Coursera, for example, bills itself as “an education company that partners with the top universities” to provide “millions of students,” with a “world-class education that has so far been available to a select few…to empower people…improve their lives, the lives of their families and communities they live in.”

On the home page of edX one reads that it “was created for students and institutions that seek to transform themselves through cutting-edge technologies, innovative pedagogy, and rigorous courses” and it “present[s] the best of higher education online, offering opportunity to anyone who wants to achieve, thrive, and grow.”

Thomas Friedman (2013) of the New York Times sees a day

where you’ll create your own college degree by taking the best online courses from the best professors from around the world—some computing from Stanford, some entrepreneurship from Wharton, some ethics from Brandeis, some literature from Edinburgh—paying only the nominal fee for the certificates of completion. It will change teaching, learning and the pathway to employment.

Hard Questions

We first describe an “ideal” MOOC and subject it to critique. This idealization is meant as an extrapolation to an extreme along an axis of increasing automation of the MOOC—a strawman.

In what ways might the ideal form of an online course divert interest and effort from valued and true pedagogical and curricular reform, or raise false hopes about possibilities for solving problems of access and affordability? In its thrust toward democratization of education, might not what’s construed as “education” via MOOCs be but a shallow imitation of what goes on in “residential” (face to face) learning?

Our objective is to test how the ideal MOOC might live up to the providers’ lofty ambitions. We argue that for more mature students (e.g., those who already have a degree) the MOOC might work in its present form, depending on the registrant’s motivation and interest. For younger students (e.g., undergraduates)—the intended audience inferred from the rhetoric—we doubt the ideal MOOC will work at all.

The Ideal MOOC

The ideal MOOC offers a set of professionally produced videotaped lectures that can be viewed anytime, anywhere; they come in 5- or 10-minute segments, are professionally done, and may include well-crafted simulations and artfully done illustrative material from relevant sources. The video can be paused to be viewed over and over, and may be accompanied by a scrolling of the lecturer’s words. No notes need be taken.

The ideal MOOC takes advantage of the interactive capabilities of digital media in the graphic simulation of phenomena and laboratory tasks.

2 www.coursera.org/about/

3 wwwedx.org/about-us
Assessment of a student’s progress and overall performance relies on machine grading. Some MOOCs may set out scoring rubrics for student evaluation of one another’s work; in the ideal case, no faculty need be involved once rubrics have been posted online.

The ideal MOOC also offers a forum for discussion, in which the student seeking clarification can pose a question and another student respond. Participation in the forum of the ideal MOOC is limited to students; there is no need for faculty intervention once the rules and protocol have been promulgated.

For economy of development effort, sequencing of lessons follows the path laid out in the syllabus of an established and proven residential course, but the start date need not be tied to the beginning of a semester or term.

In summary, with the ideal MOOC,

- lecture video clips are available online anytime, anywhere;
- students benefit from instant feedback on exercises, opportunities to redo their work, and peer evaluation;
- a self-directed discussion forum engages students with one another;
- flexibility in start date frees the courses and students from seasonal constraints; and
- there is no need for faculty or staff to intervene.

If one conceives of the MOOC in this form, then one is justified in claiming an audience of millions and, with no need for faculty or staff to intervene, the ideal MOOC promises to dramatically reduce the cost of a university education.

**Critique**

There are several things wrong with the “ideal MOOC”:

- It pays little heed to who the students are and cannot accommodate the need for face-to-face interaction among students and teachers.
- It treats knowledge as information simply to be conveyed from teacher—or rather server—to student.
- It relies on very constrained forms of exercises to engage students and assess their performance.
- There is very little information about how different, independently developed MOOCs relate or might be brought together to constitute a coherent program.
- It says nothing about the educational system within which the MOOC might be deployed (for better or worse).

We elaborate on these deficiencies in the following sections.

**MOOCs do not take account of the importance of face-to-face interaction between student and teacher.**

**Students**

The ideal MOOC is characterized by a number of challenges to the student experience.

First, it fails to take account of the importance of face-to-face interaction between student and teacher. The discussion forum offers the opportunity for student-initiated questions and commentary but in its ideal form—indeed, in its contemporary form—it is, at best, an impoverished imitation of what is encouraged in a residential classroom. Early data show that only a small percentage, on the order of 3 percent, of the total number of registrants actively participate in a discussion forum by posting questions, commenting, or debating with one another (Breslow et al. 2013).

The lack of faculty or staff intervention in the ideal discussion forum won’t work. Prompting, oversight, and monitoring are needed. But what should these entail? What are the best ways to encourage the substantial, the reflective, the probing? And to do so in a timely fashion? When, if ever, should the window on comments be closed? How responsive ought staff be to direct queries?

Second, a well-crafted suite of exercises can give students the sense that they are being personally attended to but it is all in terms set by the machinery. The student is given well-posed questions and expected to respond in a limited and defined number of ways. Correct selections are rewarded with a green check mark.

Third, there is a significant discrepancy between the promotional words of providers about the types of students who take advantage of MOOCs and the reality. The providers imply that most MOOC students are like those populating the university’s residential course of the same name. But the distribution of MOOC registrants
The BRIDGE shows an average age of about 30 and a significant number more than 50 years old. For example, a former high school English teacher in her 80s, Myra Lesser of Great Neck, New York, wrote in a letter to the *New York Times* (December 12, 2013):

A little over a year ago, I read about Coursera in *The Times*, went to the website and signed up for some courses. I had no intention of seeking any credit or taking exams, but I did watch the lectures and read a great deal of the supplemental material.

Hurricane Sandy arrived and I was housebound, but constantly engaged and enlightened by always interesting, often positively brilliant lectures. The courses gave depth to my understanding of current global realities and frequently helped me look at today’s world in an entirely different way. I have many friends who are similarly enthusiastic. In short, I think these courses are a great benefit to huge numbers of people.

In May 2013 the age distribution of registrants in all MITx courses showed an average age of 30.9, and for students in an online MIT freshman physics course 31.3 years, more than half of whom had a bachelor’s or higher degree (Belcher 2013).

The University of Pennsylvania surveyed approximately 35,000 students who had enrolled in at least one of 32 MOOCs offered on the Coursera platform and reported that “Across all geographic regions, MOOC students have very high levels of educational attainment: 83.0% of students have a post-secondary degree (2 or 4 years), 79.4% of students have a Bachelor’s degree or higher and 44.2% report education beyond a Bachelor’s degree” (Christensen et al. 2013, p. 4). The authors also found that 60 percent of the students were over 30 years of age and 10 percent were over 60. The majority (62.4 percent) were employed full-time or self-employed, and 13.4 percent reported being unemployed or retired.

Another way MOOC students differ from residential undergraduates is in their much lower rate of perseverance. Some 44,000 individuals registered for the 8.02x physics course; the second exam was taken by roughly 2,500 students; and 1,715 completed the course and received a certificate. Similarly, only about 7 percent of the students who registered for 6.002x, the electrical circuits course, earned a certificate. The large percentage of “listeners” and dropouts is characteristic of MOOCs.

**Information vs. Knowledge**

We distinguish between information as facts (e.g., the periodic table, universal constants) and as narrative (textual presentation of concepts, principles, and methods), and knowledge as the constructive renderings of information by an individual in a particular context confronted with a particular question or problem. MOOCs are best suited to the one-way transfer of information from server to student.

A textbook contains facts and narrative information that can be stored in bits on a server and transmitted to students. No ambiguity here. But knowledge—a grasp of what that information means, implies, and how it might be used—will vary from one individual to another.

Science and engineering “knowledge” is deceptively well suited for packaging and transmission via a MOOC as information, with the expectation that all students will know in the same way. Exercises that admit but a single correct answer imply as much. The deception is in the prevailing notion that textbook science and engineering theories, concepts, and methods are fixed for all time and beyond questioning. As such, the ideal MOOC’s rendering of science and engineering “knowledge” is thoroughly decontextualized, presumed as relevant to a student in rural India as to her cousin enrolled at MIT. Moreover, it fails to take account of a registrant’s prior experience; norms and values instilled through previous schooling; a registrant’s broader cultural context(s) (e.g., socioeconomic background, demographics, language skills) and how they differ, including in technical access; or individual motivations and interests.

Faculty and students who see learning as an interactive process—more like kindling a flame than depositing stores of knowledge in a bank—will not find MOOCs very attractive.

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4 The letter is available at www.nytimes.com/2013/12/17/opinion/online-courses-high-hopes-trimmed.html?_r=0.

5 The count of students in the freshman physics course (8.02x) was restricted to those who remained engaged in the course past the second exam.
Exercises and Evaluation

One of the advantages claimed for the ideal MOOC is its ability to respond instantly to a student’s submission of a solution to a problem posed online. This is true, but only for a type of problem that reinforces the image of knowledge as information to be conveyed from teacher to student.

With thousands of students enrolled in a MOOC, the opportunity for exchange with the instructor is severely limited, if not wholly absent. In a residential university science or engineering course the instructor or a teaching assistant has the opportunity to read through and evaluate a student’s method of solution and offer feedback (admittedly, not all do). The same sort of exchange is not possible for the student of an ideal MOOC.

MOOC exercises that require an essay response would seem to require a reading by staff. But even here the connection with the student is problematic. It is characteristic of the MOOC to constrain staff to communicate with students through the discussion forum, where the postings are accessible by all.

Program

The stand-alone MOOC may work very well for a mature student seeking to brush up on a subject or to broaden understanding in an area, but for students of university age and interests, a course is but one component of a program of studies leading to a degree. And on that subject, the ideal MOOC is silent.

One can imagine how a set of MOOCs in a particular domain, chosen from the rich menus of offerings of two or three prestigious universities, might be strung together on paper for degree certification by the universities themselves or a third party, but this falls far short of the learning experience at a university. A patchwork of courses does not make for a coherent program.

Alexander Astin (1999), a leading scholar of higher education, has noted that, in the voluminous research about college impact, course content turns out to be a small contributor to the growth that students experience as undergraduates. Opportunities for growth, understood in a traditional sense, are limited online.

A residential student’s learning experiences may include project-based learning, collaborative design tasks, public service, study abroad, research in a professor’s lab, and substantial advising. And we should not ignore the connections students make with their peers, social as well as intellectual, as members of a community. All this is missing from the MOOC experience.

Educational System

Consider the whole of the educational system within which the MOOC might be deployed. How will the course fit with traditional ways of teaching/learning at the university? How might it affect institutional, faculty, and student thinking about the essential ingredients of a university education? How might it change the status of faculty, the security of teaching staff? How will the value of successful completion of a MOOC be judged and by whom?

MOOC lectures may be professionally prepared, with a top scholar in the field leading the cast, and this may very well be seen by faculty who are urged (or required) to adopt the MOOC in their own teaching as a deficiency and a constraint on learning. Such faculty will have their own perspective on and approach to the knowledge domain and these may differ in important ways from those of the MOOC lecturer.

Domain knowledge and paths to knowing are not the sole property of a single scholar—there are other narratives, priorities, and approaches to the subject matter. This is more obviously characteristic of courses in the humanities, but it holds in engineering and the sciences as well. For teachers who have developed their own approach to a subject, a series of video lectures would seem a straitjacket, limiting their freedom of expression and reflection and perhaps those of their students as well.

A patchwork of MOOC courses does not make for a coherent program of study.

In fact, we have seen this reaction. In 2013 the California State University system began promoting the use of MOOCs. In reaction, the philosophy faculty at San Jose State University published an open letter objecting to the university president’s decision to add to the department’s curriculum a MOOC led by a distinguished Harvard professor. They explained,

When a university such as ours purchases a course from an outside vendor, the faculty cannot control the design or content of the course; therefore we cannot develop and teach content that fits with our overall curriculum and is based on both our own highly developed and continuously renewed competence and our direct experience of our students’ needs and abilities.

They then raised a fear others have voiced:

Should one-size-fits-all vendor-designed blended courses become the norm, we fear that two classes of universities will be created: one, well-funded colleges and universities in which privileged students get their own real professor; the other, financially stressed private and public universities in which students watch a bunch of video-taped lectures and interact, if indeed any interaction is available on their home campuses, with a professor that this model of education has turned into a glorified teaching assistant.

In an open educational market of MOOCs, students may select the most entertaining or easy courses, or those that present a position they agree with.

Will MOOCs, which to date are productions of leading universities, reduce the status and value of second-tier institutions of higher learning? Will administrations promote the adoption of MOOCs and then feel they no longer need tenured faculty to teach their students? Such developments would make for a two-tiered system that would, in turn, diminish the overall quality of the institutional choices available to students. Will a growing inequality in higher education, exacerbated by MOOCs, mirror the growing economic inequality in American society?

At present each university (and the accreditation agencies) implements quality control, while respecting academic freedom. Now consider a world where many courses are presented as MOOCs and the accreditation system proves unable to cope. When MOOCs proliferate and compete in the open market, students may be drawn to the most entertaining courses, or the easy courses, or the courses that present a position they agree with. Millions of students could receive college credit for courses of little value (e.g., they teach theories that are outdated or held in disrepute).

Such fears may be overblown, and with time and trial MOOCs may emerge as useful and valid means of education. But in the meantime much mischief can be done in an atmosphere of hubris, optimistic promises, and inadequate information; for example:

- Research on learning is limited to questions that are answered by click data (comparable to looking for the lost keys under the lamp post because that is where the light shines).
- Certification is taken over by third parties, independent of providers, resulting in a loss of control over educational content on the part of faculty.
- Costly, unpopular programs are dismantled without consideration of costs and benefits, and staff, even a university president, let go for lack of enthusiasm for the MOOC (Rice 2012).

Making More of MOOCs

MOOC providers and the media proclaim a new age of enlightenment for the youth of the world. But something is amiss. A look at who registers shows that the great majority already have at least a bachelor’s degree or its equivalent. And while a significant fraction are the age of university students (like the individuals in a producer’s corresponding residential course) only a few of these gain certification. For example, Duke University’s first MOOC, offered through Coursera, had 12,000 registrants, 11 percent of whom had at most a high school degree or equivalent. Ten people in this group successfully completed the course (Belanger and Thornton 2013).

MOOC providers need to recognize this twofold character of “the market.” On the one hand are mercenary youth of university age seeking academic credit, and on the other are self-motivated, mature, older individuals who perhaps care less about certification.

In the discussion that follows, we define “youth” as students, regardless of age, who undertake study online in pursuit of a degree. The UPenn study showed that 13.2 percent of the 34,779 students surveyed enrolled to “gain knowledge to get my degree” (Christensen et al. 2013). We define “mature” registrants as all others, the great majority of whom already have a bachelor’s degree or its equivalent.
We divide mature individuals into two groups according to their interests. The first join a MOOC because it will enhance their skills on the job or help them to obtain a new job. Christensen and colleagues (2013) reported that roughly 60 percent of those surveyed said they enrolled to “gain specific skills to do my job better” or “gain specific skills to get a new job.” These students may or may not strive to complete all the course requirements for certification.

Those in the second group register out of curiosity or learning for learning’s sake. The UPenn study showed that 50 percent of the students surveyed had enrolled out of “curiosity, just for fun.” For these individuals, certification is not a priority.

Our recommendations, accordingly, address what needs to be done to accommodate the appetites of the mature learner and what needs to be done to provide effective online learning to meet the needs of youth.

**MOOCs for the Mature**

For mature individuals who participate in a MOOC to enhance their skills on the job or help in obtaining a new job and who do not seek certification, the ideal MOOC may work fine as is. And for those who register simply out of curiosity or to learn for learning’s sake, the ideal MOOC needs little tinkering.

The providers themselves need to relax and stop treating the mature viewer as if he or she were sitting in the front row of their residential class. Let these registrants participate to whatever extent accords with their interests—watch the videos selectively, peruse the posted texts on occasion, do the exercises when their interest is piqued, and participate in the discussion forum or not.

Think of the “MOOC for the Mature” as akin to a TV series, with a single character providing the narrative and with some expectation that the viewer will participate in the exercises as the course rolls along week by week—a digital production valued for the “edutainment” it provides. For the 80-year-old former English teacher the MOOC works in just this way, and that is worth something.

**MOOCs for Youth**

The main business of universities is to educate youth. For this the passive viewing of even an enlightening digital production will not suffice.

First, the ideal MOOC won’t work for youth because university education requires more than information transfer, no matter how professionally structured. For aspiring, overtested youth, there has to be a teacher to respond to their questions, to look over their shoulder, to lead them at times, to redirect them at other times. And the teacher or professor has to know not only the subject matter through and through but also how to make effective use of the MOOC resource.

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MOOCs won’t suffice for youth because university education requires more than information transfer, no matter how professionally structured.

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Second, if one expects university faculty outside the production process to adopt and adapt the MOOC to their perspective and approach to the course material, then more openness is required. The platform should enable, if not encourage, the disassembling and reworking of the MOOC to fit the needs of faculty and students elsewhere.

The rhetoric will have to shift from promoting the MOOC as a professionally packaged, finished product to a collection of well thought out bits of content and a flexible, adaptable technology for engaging this content online by varied populations of faculty and students.

**What’s It Worth Then?**

MOOC providers should accept that, for mature course registrants, the worth of their well-done productions depends on the individual’s motivation and interest. For youth, providers need to recognize that improving university-level education will take more than the development and posting of an ideal MOOC. It requires the recognition that knowledge as information, no matter how artfully, dramatically, convincingly portrayed online, is not the driver in the education of youth. What matters is what the students themselves bring to the show, how they engage the material, under the guidance of an experienced teacher.

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7 The percentages add to more than 100 because multiple selections were allowed.
The talking head may enlighten, the multiplayer game may engage, but if students are to learn they must be challenged to reflect and apply what they see and hear to situations less well defined, more open, and even ambiguous. For this teachers with their own narrative and perspective are essential, to encourage critical thinking and reflection, and to set a coherent path through the subject matter.

References
Most funding agencies in the United States support research on technology that will benefit only wealthy parts of the world. The nano/robotic/green breakthroughs achieved in universities and other laboratories may never reach the billions of people in developing and emerging countries who need immediate solutions to improve their quality of life. The socioeconomic and technical challenges facing this segment of the global population represent a new frontier in research. New solutions to old problems are needed to deliver levels of performance similar to those enjoyed in the Global North, but at a fraction of the price to make them affordable in the Global South.

By investing in science and engineering research for international development—to address challenges in water, energy, and health, for example—funding agencies can facilitate the development of solutions for poor countries. The resulting technologies can also serve wealthy markets and provide higher value than those currently used.

Large-scale sociotechnical challenges in international development persist because there are no solutions that meet the performance and cost requirements of less developed areas. Scientific and engineering interventions for the developing world must deliver 70–100 percent of the performance at one tenth or even one thousandth of the price of western equivalents.

Academia could not ask for a more fertile bed for novel research: technical challenges that have no obvious solution and that impact millions and even billions of people, often in a life-or-death way. US intellectual power can produce unbounded research advances that address these challenges and meet the economic constraints to make them viable.

This is not a new idea—AT&T did it 100 years ago. Consumers increasingly wanted phone connectivity across the country, but AT&T was limited in how far it could run a connection—the maximum distance was from New York to Chicago. The key technical challenge was development of the capacity to amplify and repeat a weak voice signal multiple times. AT&T could have taken a tech-driven approach by manufacturing massive copper cables to transfer signals over long distances with little resistance, but this would have been too expensive for mass adoption. Instead, the company sought the help of science while keeping an eye on the business factors that would dictate the feasibility of a marketable, scalable solution. The science + economics approach led to the commercialization of the vacuum tube, which enabled intercontinental phone calls, and then the transistor, which is the backbone of all modern communications and whose inventors won the Nobel Prize. AT&T used science + economics to capture the emerging market of telecommunications.

Today’s engineers and scientists should similarly apply their talents to create the technological breakthroughs needed to transform developing countries. A background in “development” is not required. Louis Pasteur likely did not consider himself a development expert, but pasteurization allows billions of people around the world to safely drink milk every day.

If US funding agencies incorporate the constraints of developing world challenges in their requests for...
applications, they will spur innovations that benefit wealthy and poor markets alike.

For example, the US Department of Energy’s Advanced Research Projects Agency–Energy (ARPA-E) GENSETS program (GENerators for Small Electrical and Thermal Systems) is supporting research to create off-grid, 1 kilowatt (kW) electrical output combined heat and power systems that cost $3,000. But Chinese-made 3 kW diesel generators already in use throughout the developing world cost only $500. What if ARPA-E posed the exact same challenge, with the same efficiency targets and promotion of novel technology, but required solutions that were affordable and implementable in developing countries? The agency could expand the impact of the resulting technology without compromising potential benefits to American taxpayers.

Furthermore, if the United States invests in technologies for emerging markets, it will spur US industry by enabling firms to increase their global reach and engage new customers.

As a wealthy nation, and one that has a long-standing commitment to international aid, it is the duty of the United States to shrewdly invest financial and intellectual resources to create development solutions that will lift billions of people out of poverty and substantially raise their standard of living. To do this, we engineers and scientists cannot simply adapt our western solutions; we have to disrupt by creating the high-performance, low-cost breakthroughs needed in developing and emerging markets.

Funding agencies should judge research by absolute gains in not only performance but also performance/price. By investing in research for the developing world that will deliver fundamentally improved performance at a better price, the United States can positively impact the lives of people at home and abroad.
An Interview with . . .

US Representative Paul D. Tonko

Ron Latanision (RML): We appreciate your making time to speak with us. We are especially pleased to have a sitting member of Congress talk with us, and one who is a trained engineer.

Rep. Paul D. Tonko (PDT): Thank you. It is rather interesting because you see the complexities of not only our society but the international economy. You understand the kind of analytical approaches that need to be taken. I think engineers should be front and center at the public policy table.

RML: I am very much of the same mind. We wanted to ask you, first, how did you come to work toward a degree in mechanical and industrial engineering? Second, how did that lead you to your interest and entry into public life?

PDT: People talk about that as two separate components, but for me it is very logical and very much represented through the global race on space. President John F. Kennedy, after a defeat for this nation—landing on our backside with the Sputnik moment—got us all developing and igniting this passionate resolve to go forward and win the global race on space. Everywhere you went you heard it talked about—in the classroom, at the playground, at church, at home; grandparents, parents, teachers, community, all talking about it. It was the global race on space. It was the Sputnik moment: ‘We lost. We have got to win this now.’

That impacted me in two very prominent ways: politics being noble, with a small n—having the boldness to change things and direct things and fuel things—and engineering as a matter of conquering space.

So when people ask me, ‘How did you, an engineer, find yourself in politics?’—it happened under the singular dynamic of the global race on space. It was the passionate appeal, and again the passionate resolve in response to that appeal, of the nation in a multipartisan way, to win this race of “US versus USSR.”

Today, we have a president tossing the same challenge our way, but this time it is not the United States versus another competitor nation, it is the US versus dozens of countries that are going to pass us by if we fail to resolve to provide the resources to make this happen. Those resources are physical, capital, and human infrastructure, and the human infrastructure is lacking. We need to produce far more engineers. As a society we are woefully underproducing the engineers we need to win this race of innovation.

RML: To follow that up for a moment, of your colleagues in the House and the Senate, how many members are you aware of that have educational backgrounds in either science or engineering?

PDT: I would say there are probably 10 in the two houses. I am guessing.

RML: I thought it was on that order of magnitude. When you consider the total population of 535 members, that is a pretty small representation, isn’t it?

Paul Tonko has represented New York’s 20th congressional district—which comprises Albany and Schenectady counties and portions of Montgomery, Rensselaer, and Saratoga counties—since he was elected in November 2008.
PDT: Yes. I am reminded of Steinmetz, who was very involved in his local community, I believe on the school board. When he was quizzed about it, he said the first people in line to run for public office should be engineers because they are analytical, they are problem solvers, and I think it is natural for them.

RML: How do we encourage more engineers and scientists to do that?

PDT: I think we remind them that engineering is what transforms us. Engineering is what embraces the pioneer spirit. Engineering is what unlocks the untold possibilities. When you put it into that kind of romance not only are they great problem solvers, but the catalysts—the catalytic ingredient that creates that swirl, that transformation opportunity. So it is important to have us there because these are complex issues that require an analytical approach—it needs to be based in science and in fact.

CAMERON FLETCHER (CHF): What opportunities do you get to talk with engineers and particularly engineering students, since you are talking about human capital?

PDT: I am lucky because I keep in contact with my alma mater, Clarkson University in upstate New York. I also have a great collection of engineer professionals and engineering students at Rensselaer Polytechnic Institute and at other campuses—in the State University of New York (SUNY) system, at the community colleges, at Union College. I am fortunate because we have the infrastructure that either employs or educates the engineering community. That is helpful.

Going into the high schools, I see commitments in my local region that are encouraging. The region is one of the five hottest hubs in the country of clean energy innovation and high-tech job growth, and because of that I think we have become a very transitional area where we are attaching to our high-tech partners space for students. We have got them learning right at their centers of work. We have got high schoolers who are developing their intellect. We’ve got a high-tech campus, a green tech campus—we’re dubbed the “Tech Valley.”

The tone that has been established and the working practical experiences are now allowing for this opportunity. I go to a number of student robotics competitions, see summer camps based on robotics. That inspires me and challenges me to get out there and find the resources, develop the public policy as we have developed our ETEA legislation.

It is a defining moment when you see how aggressively the need has grown for STEM-educated professionals in the past decade alone—and how that demand continues to grow.

CHF: With your involvement in appropriations, of course, you can directly support students and technical programs at the university level. Do you also play a sort of cross-pollinating role between students and industry?

PDT: I’ve developed good working relationships with the private sector. We are constantly doing tours at these facilities. We have a small business roundtable. A lot of the innovative startups are small and medium-size businesses. We deal with industries as large as GE, with its international renewable center, and we have worked with them on the efficiency of wind turbines or natural gas–fed turbines. All of that dialogue is a concept or a bit of reality through which you can introduce students.

We are always encouraging a match in student mentoring so that someone can express the joy of working as an engineer. If we don’t see the profession on display we leave it to imagination—and perhaps imagination doesn’t take us there. It’s important for students to see the exhilarating quality of being an engineer, for them to come in contact with those active verbs like invent, discover, explore, and design.

It’s important for students to see the exhilarating quality of being an engineer, to come in contact with verbs like invent, discover, explore, and design.

1 Charles Proteus Steinmetz (April 9, 1865–October 26, 1923) was a German-born American mathematician and electrical engineer who served as president of the Board of Education of Schenectady.

2 Rep. Tonko introduced the Educating Tomorrow’s Engineers Act in February 2015.
RML: In your district you have, as you pointed out, a convergence of not only educational institutions but also technology-based companies such as General Electric.

PDT: You know, it is very difficult but in addition to connecting businesses with students, we are trying to connect parents with students. My area includes the eastern mouth of the Erie Canal, which, as we all know, became a spark that ignited industrial revolution in a westward movement—the Barge Canal/Erie Canal produced that early era of manufacturing.

Now we need engineers in today’s innovation economy, which means advanced manufacturing. If we are to harness the potential of an American manufacturing sector that continues to evolve and expand, we must strengthen the relationships between teachers, parents, students, and the business community—and promote the reality that today’s manufacturers aren’t the same as even ten years ago. It is advanced and rising quickly and in totally different settings. I see manufacturing in my district where you can eat off the floors and where it is the intellectual capacity of the engineer that is winning the race to not necessarily do it cheaper but do it smarter.

RML: Right. I continue to hear from friends at companies like General Electric and Boeing, for example—air frame manufacturers on the one hand and engine manufacturers on the other—that the calculus that involves the retirement of the current generation of engineers and the pool of the engineers in our education system leaves them very concerned about where they are going to find the next high-temperature oxidation expert or the next aluminum metallurgy expert. Do you also hear that?

PDT: Absolutely. I get concerned when I look at the statistics. As legislators, the decisions that I anticipate are going to be difficult. I did not assume coming into this job that life is easy. You have difficult moments, difficult decisions, and boldness that needs to be embraced. When the stats speak to you, as leaders we should be ahead of the curve. Whether that’s the education curve, the manufacturing curve, the innovation curve, whatever it is, we should be ahead of the curve.

Investing, as I recommend we do through the ETEA, is of absolutely critical importance. If we need to modify and intensify and lift what we are doing today, then let us do it. And if we have science and language and math but not engineering as part of the standards, let us upgrade. Let’s make it very clear. Let’s not leave it to interpretation. Let’s be very defined in our statute that we want standards developed for engineering, that we want staff training, routine upgrading for professional skills for the classroom. Make those resources available, have reviews done with research.

Are we reaching students the way we need to to encourage them to consider engineering? Even if you don’t follow that career path, developing analytical skills and problem-solving teams in the classrooms teach the students an awful lot.

RML: All that leads me to ask about the direction of university research in the United States. Maybe the corollary would be direction of funding from the traditional agencies that fund research at universities.

As leaders we should be ahead of the curve, whether it’s the education curve, the manufacturing curve, the innovation curve.

PDT: I have to tell you it is very distressing around here to witness how clueless we are at times as a leadership body that should be, again, embracing leadership. We don’t enhance areas like the energy-efficiency, renewable energy component of the Department of Energy (DOE), we don’t invest in the Advanced Research Projects Agency–Energy (ARPA-E).

When I first came here ARPA-E had been established but never funded. So the fight in 2010 with the America COMPETES Act was to fund ARPA-E. Now we have a track record with a concept, whereas before we had only the concept. Why would you not grow ARPA-E? That is how we as a nation maintain our leadership quality, with the intellectual capacity of our citizens.

If we are going to invest in the intellect, stretch the educational development of our young minds—if we are going to cultivate engineers—then we need to make heavy investments in research to unleash all sorts of opportunities, as we had in the Defense Advanced Research Projects Agency (DARPA).

From the days of finding a polio vaccine to all that we are doing now for energy innovation—transformation and efficiency and conservation—all of that should be
encouraged through sound public sector investment in research, R&D, and partnering with the private sector, where risk may be perceived as too great. The public sector can share some of that risk, and should be there where the private sector won't go. There have been plenty of cases in US history of that.

I don't want to hear, 'Well, some research investment has failed.' By its very definition, by its very nature, in the research area failure is the down payment to success. Without failure you would never realize a new product line or the best product line. So I don't want to hear failure as the rationale to not invest in research.

Back to the space race of the 1960s that ignited my interest. It wasn’t just landing a person on the moon, it wasn’t Neal Armstrong staking the American flag into the surface. It was unleashing in every sector of our economy growth and high tech and new opportunity and hope. Hope. This is our down payment for hope.

RML: Do you think that Congress is of a mind to act on some of the things you have just described?

PDT: I am concerned that there are far too many members that are not. The tough thing in a legislative arena is that you broad-brush. But I want people to understand that there are those of us in Congress who believe in investment—investment in research, investment in education, investment in higher education, investment in innovation, investment in the cultivation of engineers.

Investment in research, education, innovation, and in the cultivation of engineers is essential for a world-leading nation to keep its status.

Those investments are understood with very much validation and justification, a lucrative dividend follows. For those who see it as spending that needs to be cut, I think they are not seeing it for what it is. It is an order of investment that is essential for a world-leading nation to keep its status.

RML: I agree with your sense as well, Paul, of a public-private partnership in making all of this happen. If companies like Boeing and GE were to express their concerns about hiring the kinds of people they need going forward, given this calculus of retirement and hiring, I think that is an important statement. But I don’t see that publicly. I hear it from friends and colleagues. I would be much happier if some of our major corporations were to speak out very deliberately on this subject.

PDT: I think the messaging for these concepts needs to come from outside as well as from within. From within, oftentimes we are already prelabeled with our stripes. An independent audience can grow our economy, grow the dignity of having a job. Hearing from those groups, I agree, is absolutely essential. Let’s face it, their beginnings were with people of invention and innovation.

I represent “the electric city,” Schenectady, New York: headquarters of GE, home to Steinmetz and Thomas Edison and George Westinghouse. These names are significant for having enhanced people’s quality of life—by providing services and products that have been lifesaving, that have increased our comfort or directly impacted our quality of life in other ways. These are major, major outcomes that came with investment.

This whole order of thinking where government is too big, government is the problem, government needs to be cut—tell that to other nations where there are sound public-private partnerships and where they are committing government resources matched by private sector support, to be as strong as they can be in this global race.

To me it should not be a question of if, it should be about how great an investment, how meaningful and effective an investment, and how we are going to bulk up so that we can win this race. Because whoever wins the global race on clean energy innovation will be the kingpin of the international economy.

RML: Do you have contact with the president’s science advisor John Holdren on any of these issues?

PDT: We have contact with the appropriate agencies and with the White House team and work routinely with folks. I think they know that we are driven by the investments that we need to make. For instance, the National Network for Manufacturing Innovation (NNMI) initiative that the president fostered, we are championing that effort and want to make sure it stays in budgets. This type of initiative goes after innovative concepts that require sound minds and sound training in development to go forward.
If we don’t create some sort of cultivating arena that takes our intellectual capacity and puts it to work for our nation and others in the world, then we are failing in our efforts here.

RML: Paul, I know we have a limited amount of time given your busy schedule. Is there any message you would like to give the members of the National Academy of Engineering?

PDT: I have a couple of messages. Get robust in your advocacy. Know that you are tremendously needed. If there is any group that should be loud and outspoken and forceful, it is the engineers. We have got highway infrastructure, transportation infrastructure, clean drinking water infrastructure, water sewer infrastructure, to name a few that are not being addressed. Engineers need to speak to these issues not only forcefully but technically and with great information at their fingertips.

My really great friend, Representative John Lewis from the state of Georgia, who was severely impacted and injured on the Pettus Bridge in Selma 50 years ago, led a walk over the bridge again this year for a 50th anniversary celebration. He has reminded me in our “brother Paul/brother John” working relationship, ‘Brother Paul, make trouble, good trouble.’ It is time for the engineers to make good trouble, to stir the pot. Talk about growing the amount of engineers we require, about using those engineers in public policy format and using their rationale to grow the resource commitment that we need to make it as a nation.

We need sound engineering savvy, we need energy policy transformation, infrastructure improvement, research levels that are enhanced so that we can go forth and be that sense of hope. Engineers equal hope to the people of this country, working their academic prowess to the public policy arena and through the innovation arena.

RML: That is a wonderful message. We will certainly transmit that to our members.

CHF: And Paul, a couple of publications will be of particular interest to you if you have not already seen them. The Academy recently released Making Value for America, about the new landscape for manufacturing and what is needed. If you have not seen it, I will pop that in the mail to you. You will also be interested to see the summer issue of the Bridge, which is specifically devoted to energy issues; at least one or two of the articles address the role of the federal government in energy. And the fall issue of the Bridge will be devoted to the changing status of manufacturing.

PDT: Wonderful. I have to run. I enjoyed the half hour we had to share.
Asad M. Madni, independent consultant and retired president, chief operating officer, and CTO of BEI Technologies Inc., has been selected an Eminent Member of IEEE–Eta Kappa Nu. The induction ceremony will take place November 20 in New Brunswick. The designation is the organization’s highest membership category and is conferred on a select few whose outstanding technical attainments and contributions through leadership in the fields of electrical and computer engineering have resulted in significant benefits to humankind.

Pol D. Spanos, L.B. Ryon Endowed Chair in Engineering, Rice University, has been honored for his contributions as an outstanding leader in the engineering profession by being named to the ASCE 2015 Class of Distinguished Members. Dr. Spanos is an expert in the development of techniques for predicting the dynamics and reliability of constructed facilities subject to loads induced by earthquakes, ocean waves, and winds, and has made significant contributions to the field of engineering mechanics.

The Next MacGyver

In celebration of National Engineers Week in February 2015, the National Academy of Engineering and the University of Southern California’s Viterbi School of Engineering, in collaboration with the MacGyver Foundation and Lee Zlotoff (creator of the TV series “MacGyver”), launched a worldwide crowdsourcing competition called “The Next MacGyver.”

Sponsored by the United Engineering Foundation, the project sought ideas for a scripted television show featuring a female engineer character in a leading role. The goal of the competition was to create a historic TV series that inspires young people, especially women, to pursue careers in engineering.

Almost 2,000 submissions were received and, through a screening process involving judges from both engineering and entertainment, 12 finalists were selected. The finalists hail from as far away as Australia and are practitioners and scholars in STEM (science, technology, engineering, and mathematics) fields, seasoned and first-time writers, students, and an Internet personality. Show concepts spanned the genres of science fiction thriller, comedy, classic spy, historical setting, and interactive crime drama.

During a live pitch event in Los Angeles on July 28, the finalists presented their show ideas along with concept art and the judges selected five winners. They each received $5,000 and were paired with a successful Hollywood TV producer who will mentor them in creating an original TV pilot script. Expert engineers will also be involved in helping to develop the engineering-focused storylines.

The five winners and their mentors are:

Name: Beth Keser, San Diego
Mentors: Lori McCreary, CEO and founder of Revelations Entertainment and president of Producers Guild of America (“Madam Secretary,” “Through the Wormhole”)
with Morgan Freeman); and Tracy Mercer, VP of development, Revelations Entertainment
TV Concept Title: Rule 702
Name: Jayde Lovell, New York City
Mentor: Roberto Orci, writer/producer (“Star Trek,” “Scorpion,” “Sleepy Hollow,” “Hawaii Five-O,” “Fringe”)
TV Concept Title: SECs (Science and Engineering Clubs)
Name: Miranda Sajdak, Los Angeles
Mentor: Clayton Krueger, senior vice president of television, Scott Free Productions (“3001: The Final Odyssey”)
TV Concept Title: Riveting
Name: Craig Motlong, Seattle
Mentor: Anthony E. Zuiker, creator and executive producer of the CSI franchise
TV Concept Title: Q Branch
Name: Shanee Edwards, Los Angeles
Mentors: America Ferrera, actress/producer (“Ugly Betty,” “Sisterhood of the Traveling Pants”); and Gabrielle Neimand, Take Fountain Productions
TV Concept Title: Ada and the Machine

More information on the winners and their show ideas is available at thenextmacgyver.com.

2015 China-America Frontiers of Engineering Held at Beckman Center

The fourth China-America Frontiers of Engineering Symposium was held June 1–3 at the Arnold and Mabel Beckman Center in Irvine, California. NAE member Gang Chen, the Carl Richard Soderberg Professor of Mechanical Engineering at the Massachusetts Institute of Technology, and Zhuhua Zhong, secretary-general of the Chinese Academy of Engineering, cochaired the symposium.

Consistent with the design of the bilateral FOEs, this meeting brought together approximately 60 engineers, ages 30 to 45, from US and Chinese universities, companies, and government labs for a 2½-day meeting where leading-edge developments in four engineering fields were discussed. The four session topics were Advanced Manufacturing, Big Data, Clean Water, and Devices for Health Care.

China and the United States are the world’s two largest manufacturing nations, accounting for 40 percent of world manufacturing in 2012. Advanced manufacturing has been defined as “a family of activities that depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences” (PCAST, 2011; Report to the President on Ensuring American Leadership in Advanced Manufacturing). Talks in this session highlighted recent developments in advanced manufacturing as well as future innovative product and process technologies. The first speaker discussed digital manufacturing, the use and coordination of information, automation, computation, software, sensing, and
networking in manufacturing, with an emphasis on the impact of digital manufacturing on creating links between designers and makers. This was followed by talks on origami structures and their engineering applications, nano- and microscale 3D bioprinting, and applications of micro-/nano- and precision manufacturing technologies.

In the second session, on Big Data, presenters considered how the science and practice of big data can positively impact our lives and what tools and techniques are required to develop such systems. The opening speaker described how big data can be used for societal challenges such as recognition of counterfeit goods, disease surveillance, and detection of events from news reports. This was followed by a presentation on the use of electric taxi trajectory data to determine optimal placement of electric vehicle charging stations to minimize travel and waiting time. Handling a large amount of data requires building sophisticated distributed software and hardware infrastructure. The talk in this area covered China’s Big Search in Cyberspace project and how to construct knowledge warehouses, understand the user’s search intent expressed in natural language, match it to the knowledge warehouse, and ensure that the search process is secure. The final speaker talked about the principles of deep learning; the common technique behind recent breakthroughs in object recognition, speech recognition, and understanding natural language; and Google Brain.

Water supply systems are an essential component of public health infrastructure development, and over the past 100 years there has been an extensive effort to install piped, treated, large-scale centralized water and wastewater systems in the United States and China. But these systems are associated with challenges involving maintenance and the removal of disease-causing pathogens. Presentations in this session addressed decision making about the efficacy of smaller-scale water and wastewater systems in the southeastern United States and Cambodia; design and construction of an innovative biocatalytic electrolysis-stimulated biotreatment technology to remove recalcitrant compounds from wastewater; research on the transport of Cryptosporidium through watersheds and the water treatment network; and control of arsenic in drinking water.

Advances in devices for health care, the topic of the last session, occur at the intersection of almost every field of engineering. For example, developments in materials, communication, and computation have been combined with advances in assay techniques, microfluidics, and manufacturing to bring new classes of medical devices to market and to create a pipeline of exciting technologies for the future. The session started with a presentation on new materials—with particular emphasis on material properties, biocompatibility, and advanced manufacturing methods—that enable wearable conformal diagnostic devices that provide real-time continuous monitoring of individual patients. This was followed by a talk on technologies that allow mobile diagnosis and treatment of disease and the importance of these techniques for global health applications. The discussion of wearable and mobile diagnostic devices was expanded by the third speaker, who covered innovations in energy harvesting and power generation as promising ways to power distributed diagnostic devices in the future. The session concluded with a report of the latest biomedical imaging techniques and technologies, including in vivo optical traps.

In addition to the formal presentations, a poster session preceded by flash poster talks took place on the first afternoon, serving as both an icebreaker and an opportunity for participants to share information about their research and technical work. The posters remained on display throughout the meeting, prompting further discussion and exchanges during the coffee breaks. On the second afternoon, attendees were taken to Laguna Beach for walking tours in small, preassigned groups of Chinese and American participants. This allowed attendees to get to know each other in a more informal setting and to see some of the beautiful southern California coast.

It is an FOE tradition to have a dinner speech by a senior-level engineer on the first evening of the meeting. At the 2015 CAFOE symposium NAE member Ken Q. Xie, founder, chair, and CEO of Fortinet, Inc., talked about the role of entrepreneurship in his career and cited the factors that make the United States a fertile ground for entrepreneurs, such as a university environment that supports the start of new companies by faculty and students and close connections with industry that can provide critical startup funding. He said the most important lesson he learned from his experience with his first company—a lesson he has carried into subsequent endeavors—is that building trust with partners and customers is the key to a successful business.
The program, list of attendees, and presentation slides are available at the CAFOE link at www.naefrontiers.org.

Funding for this activity was provided by The Grainger Foundation and the National Science Foundation. The next CAFOE meeting will take place in China in 2017.

The NAE has been hosting an annual US Frontiers of Engineering meeting since 1995, and, in addition to CAFOE, has bilateral Frontiers of Engineering programs with Germany, Japan, India, and the European Union. All the FOE symposia bring together outstanding engineers from industry, academia, and government at a relatively early point in their careers (participants, speakers, and organizers are 30–45 years old). The meetings provide an opportunity for attendees to learn about developments, techniques, and approaches at the forefront of fields other than their own, something that is increasingly important as engineering has become more interdisciplinary. The program also facilitates the establishment of contacts and collaboration among the next generation of engineering leaders.

For more information about the activity, or to nominate an outstanding engineer to participate in future Frontiers meetings, go to www.naefrontiers.org or contact Janet Hunziker at jhunziker@nae.edu.

**NAE and Georgia Tech Host Roundtable on Disaster Preparedness**

On August 5 the NAE and Georgia Institute of Technology cohosted a roundtable to explore the state of disaster preparedness in the United States. The event, “10 Years after Katrina: Are American Cities Ready?,” held at the Academies’ Keck Center in Washington, DC, brought together distinguished panelists, media representatives, and invited guests to discuss what might be done to improve the way communities and state and federal governments respond when disaster strikes.

Hurricane Katrina was the costliest hurricane ever recorded. When it struck the coastline of Louisiana in August 2005, it caused $108 billion (2005 USD) in property damage. At the time, many felt that the level of devastation wrought by Katrina was unique to New Orleans, a function of the city’s peculiar geography and topography. However, Hurricane Sandy demonstrated that other major US coastal cities, long thought to be beyond the reach of major hurricanes, are extremely vulnerable. Roundtable attendees discussed the implications of this new awareness of the scope of our vulnerability and specific lessons from the Katrina and Sandy storms for disaster preparedness at the national, regional, and community levels.

The need for more communities and regions of the country to prepare for earthquakes was also discussed. Although most people think of highly destructive earthquakes as solely a West Coast problem, the fact is that various parts of the country sit on major fault lines and thus are prone to large (if much less frequent) earthquakes as well. A magnitude 7.0 earthquake in Charleston, South Carolina, in 1886 was cited as an example: it caused 60 deaths and $5–6 million in damage to 2,000 buildings in the southeastern United States.

Roundtable panelists and attendees agreed that it is essential for all communities to actively discuss and make preparations for potential disasters.

NAE President C. D. Mote, Jr. gave opening remarks. Expert panel members were Greg Baecher, Glenn L. Martin Institute Professor of Engineering, University of Maryland; Lieutenant General Thomas Bostick, chief of engineers and commanding general, US Army Corps of Engineers; G. Wayne Clough, president emeritus, Georgia Institute of Technology, and former secretary of the Smithsonian Institution; Reggie DesRoches, chair, School of Civil and Environmental Engineering, Georgia Tech; Alton D. Romig, Jr., NAE executive officer; and Lauren Sauer, associate director, National Center for the Study of Preparedness and Catastrophic Event Response, Johns Hopkins University. The experts were joined by three seasoned journalists who have written extensively about natural disasters: Seth Borenstein with Associated Press, Alan Neuhauser with US News & World Report, and Thomas Sumner of Science News. The roundtable was moderated by Steven Norris, a member of Georgia Tech’s Communications team and a former journalist who covered Hurricane Katrina recovery on the Gulf Coast.
EngineerGirl Essay Contest Winners

The National Academy of Engineering has announced the winners of its 2015 EngineerGirl essay competition. This year's international contest asked students in grades 3–12 to describe the engineering behind a technology used in playing, scoring, or training for a chosen sport. “Engineering determines the way we live, from our health and safety to enjoying our favorite activities,” said NAE president C. D. Mote, Jr. “This year’s essay contest submissions showcased brilliantly the wide-ranging impacts of engineering contributions to our happiness.”

Prizes (first, second, third place and honorable mention) were awarded to students in three categories based on grade level. Abby Mauer, a fifth-grader at Sacred Heart of Jesus Catholic School in Shawnee, Kansas, placed first among third- to fifth-grade students for her essay on improving a volleyball through engineering. Seventh-grader Rebecca Yermish from Frances S. DeMasi Middle School in Marlton, New Jersey, won first place among entries from grades 6–8 for her essay describing the roles of design and manufacturing/process engineers in developing arrows for archery. Among 9th- to 12th-graders, Isabelle Breier, in the 11th grade at Hopkins School in New Haven, Connecticut, placed first for her explanatory essay about engineering innovation in ballet shoes.

To see all the winning essays on topics as varied as basketball, fencing, skiing, and rock climbing, visit the EngineerGirl website at www.engineergirl.org/2015winners.aspx.

Commonweal Foundation Interns Join the Program Office

During the summer of 2015 the NAE Program Office hosted two Commonweal Foundation interns.

PHILLIP COLEMAN was assigned to three projects during his internship—Engineering Societies and Engineering Education, Frontiers of Engineering Education (FOEE), and Making Value for America—for which he did preliminary research and extensive literature reviews. A sophomore studying electrical engineering at Andrews University in Berrien Springs, Michigan, Phillip plans to use his internship experience on projects with the campus chapter of Engineers without Borders. He is interested in engineering policy and wants to use engineering for humanitarian projects. When he’s not in school or working, he is a classical pianist (Rachmaninoff is his favorite composer) and a movie enthusiast.

BRIANA SYMONE MARSHALL worked on activities related to the EngineerGirl website (www.engineergirl.org) and the E4U2 video contest (www.nae.edu/e4u2), among others. She is a recent graduate of Takoma Academy in Silver Spring, Maryland, where she was president of both the junior and senior classes. This fall she is beginning studies at Oakwood University in Huntsville, Alabama, with plans to double major in civil engineering and applied mathematics. Briana enjoys travel, community service, and learning new things; in high school she travelled extensively—to Belize, Bermuda, France, Greece, Italy, Jamaica, Spain, Tanzania, and the United Kingdom. This summer was her first as an intern at the National Academies of Sciences, Engineering, and Medicine in a four-year program. She is grateful for the opportunity to intern with the NAE Program Office and excited to continue learning during her internship over the next three summers.
Calendar of Meetings and Events

September 14–16  Chinese Academy of Engineering—National Academy of Engineering—Royal Academy of Engineering
Global Grand Challenges Summit
Beijing

September 18  Noon deadline EDT for submission of Exemplary Engineering Ethics Education Activities

October 2–3  NAE Council Meeting

October 3  NAE Peer Committee Meetings

October 4–5  NAE Annual Meeting

October 5  Forum: Grand Challenges for Engineering: Imperatives, Prospects, and Priorities

October 8  2016 Gordon Prize Final Committee Meeting

October 12–16  Convocation of Academies of Engineering and Technological Sciences
New Delhi, India

October 25–28  Frontiers of Engineering Education
Beckman Center
Irvine, California

December 2–3  2016 Election Committee on Membership Meeting

All meetings are held in National Academies facilities in Washington, DC, unless otherwise noted.

In Memoriam

HARL P. ALDRICH JR., 91, retired chairman, Haley & Aldrich, Inc., died November 24, 2014. Dr. Aldrich was elected to the NAE in 1984 for fundamental contributions to understanding of freezing problems and preloading techniques, also leadership in development of geotechnical engineering practice.

WILLIAM F. ALLEN, 95, retired chairman, Stone & Webster, Inc., died September 21, 2014. Mr. Allen was elected to the NAE in 1986 for creative design and analysis of advanced electric generating stations, and for outstanding leadership of a large, innovative engineering construction company.

EUGENE E. COVERT, 88, T. Wilson Professor of Aeronautics Emeritus, Massachusetts Institute of Technology, died January 15, 2015. Dr. Covert was elected to the NAE in 1980 for contributions to aerodynamics, aeronautics, education of engineers, and national security.

ROBERT J. CREAGAN, 95, retired consulting engineer, Energy Systems Analysis, Westinghouse Electric Corporation, died November 1, 2014. Dr. Creagan was elected to the NAE in 1981 for design and economic evaluation of the first full-scale, economically viable, pressurized-water reactor, and for chemical-shim reactor control.

DIARMUID DOWNS, 91, former chairman, Ricardo Consulting Engineers plc, died April 23, 2014. Sir Diarmuid was elected to the NAE as a foreign member in 1987 for significant contributions to the understanding of combustion processes in internal combustion engines and to advances in engine design.

ROBERT A. DUFFY, 93, retired president and CEO, the Charles Stark Draper Laboratory, Inc., died February 4, 2015. Brig. Gen. Duffy was elected to the NAE in 1980 for contributions to inertial guidance and oceanographic systems.

JAMES A. FAY, 91, professor of mechanical engineering emeritus, Massachusetts Institute of Technology, died June 2, 2015. Dr. Fay was elected to the NAE in 1998 for contributions to fluid and plasma dynamics, combustion, environmental technology, and recent creation of the first hypermedia fluid mechanics text.

ALEXANDER FEINER, 86, retired chief scientist, AT&T Bell Laboratories, died August 30, 2014. Mr. Feiner was elected to the NAE in 1984 for innovative concepts in state-of-the-art technology and their successful implementation in new telecommunications equipment.

JOHN H. (JACK) GIBBONS, 86, former assistant to the president for science and technology and former director, Office of Science and Technology Policy, died on July 17, 2015. Dr. Gibbons was elected to the NAE in 1994 for leadership in a broad spectrum of initiatives toward
the development and communication of national policies for technological issues.

MUJID S. KAZIMI, 67, TEPCO Professor of Nuclear Engineering, Massachusetts Institute of Technology, died July 1, 2015. Prof. Kazimi was elected to the NAE in 2012 for contributions to technologies for the nuclear fuel cycle and reactor safety.

ERNEST S. KUH, 86, William S. Floyd Jr. Professor Emeritus in Engineering, University of California, Berkeley, died June 27, 2015. Dr. Kuh was elected to the NAE in 1975 for contributions to circuit and system theory.

JOHN L. LUMLEY, 84, Willis H. Carrier Professor of Engineering Emeritus and Graduate Professor of Mechanical Engineering and Aerospace Engineering, Cornell University, died May 30, 2015. Dr. Lumley was elected to the NAE in 1991 for significant contributions to the understanding of turbulent and non-Newtonian flows.

WILLIAM J. McNUTT, 87, retired president, Berkshire Transformer Consultants, Inc., died November 14, 2014. Mr. McNutt was elected to the NAE in 2000 for contributions to the design and development of large power transformers.

DALE D. MYERS, 93, former deputy administrator, NASA, died May 19, 2015. Mr. Myers was elected to the NAE in 1974 for leadership in mastery of space flight and applications of aerospace technology.

WILLIAM N. POUNDSTONE, 89, retired executive vice president, Consolidation Coal Company, died July 3, 2015. Mr. Poundstone was elected to the NAE in 1977 for contributions to the development of improved underground coal mining technology.

JAMES B. RESWICK, 90, retired director, Division of Research Sciences, National Institute of Disability and Rehabilitation Research, US Department of Education, died March 13, 2013. Dr. Reswick was elected to the NAE in 1976 for contributions as a teacher and designer in the fields of mechanical, control, and biomedical engineering.

HERBERT B. ROTHMAN, 91, retired chairman, Weidlinger Associates Inc., died July 26, 2015. Mr. Rothman was elected to the NAE in 1990 for outstanding contributions to the design and rehabilitation of hundreds of bridges of all types and for exceptional contributions to the understanding of wind effects of complex structures.

BOB E. SCHUTZ, 74, professor of aerospace engineering and engineering mechanics, University of Texas at Austin, died June 7, 2015. Dr. Schutz was elected to the NAE in 2014 for contributions to the use of satellite laser ranging and global positioning system tracking to study Earth system dynamics.

DONALD M. SMYTH, 85, Paul B. Reinhold Professor Emeritus of Materials Science and Engineering and of Chemistry, Lehigh University, died April 25, 2015. Dr. Smyth was elected to the NAE in 1996 for contributions to the solid state chemistry of electronic components based on ceramic materials.

GÜNTER SPUR, 84, professor, Technical University–Berlin, died August 20, 2013. Dr. Spur was elected to the NAE as a foreign member in 1981 for notable contributions to computerized process-planning and production-control systems and leadership in research in manufacturing engineering.

MORGAN C. SZE, 98, retired consulting engineer, died March 20, 2015. Dr. Sze was elected to the NAE in 1976 for contributions to the technology of petroleum refining and petrochemical process design and manufacture.

EUGENE P. WILKINSON, 94, retired president and CEO, Institute of Nuclear Power Operations, died July 11, 2013. Vice Adm. Wilkinson was elected to the NAE in 1990 for outstanding leadership in naval nuclear propulsion programs and improvement in the operation of commercial nuclear power plants.
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Sustain the mission and work of the NAE. Make a significant contribution to endow our future…and it’s easier than you might think. Here are some strategies that can benefit you and build our endowment.

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We would be happy to talk with you and provide a free illustration of benefits.
The following reports have been published recently by the National Academy of Engineering or the National Research Council (NRC). Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street NW–Keck 360, Washington, DC 20001. For more information or to place an order, contact NAP online at <www.nap.edu> or by phone at (800) 624-6242. (Note: Prices quoted are subject to change without notice. There is a 10 percent discount for online orders when you sign up for a MyNAP account. Add $6.50 for shipping and handling for the first book and $1.50 for each additional book. Add applicable sales tax or GST if you live in CA, CT, DC, FL, MD, NC, NY, PA, VA, WI, or Canada.)

Review of the Everglades Aquifer Storage and Recovery Regional Study. The Florida Everglades is a large and diverse aquatic ecosystem that has been greatly altered over the past century by an extensive water control infrastructure designed to increase agricultural and urban economic productivity. The Comprehensive Everglades Restoration Plan (CERP), launched in 2000, is a joint effort of the state and federal government to reverse the ecosystem’s decline. Water storage is a critical component of the plan, and the CERP calls for drilling more than 330 aquifer storage and recovery (ASR) wells to store up to 1.65 billion gallons per day for recovery during dry periods. To address uncertainties about regional effects of large-scale ASR implementation in the Everglades, the US Army Corps of Engineers (USACE) and the South Florida Water Management District conducted an 11-year ASR study of the hydrogeology of the Floridan aquifer system, water quality changes during aquifer storage, possible ecological risks, and the regional capacity for ASR implementation. The USACE asked the NRC to review the ASR Regional Study Technical Data Report and assess progress in reducing uncertainties related to full-scale CERP ASR implementation. This report considers the validity of the data collection and interpretation methods, scaling from pilot to regional-scale ASR application, and the adequacy and reliability of the study as a basis for future applications of ASR.

NAE member R. Rhodes Trussell, chair and CEO, Trussell Technologies Inc., was a member of the study committee. Paper, $42.00.

Review of NASA’s Evidence Reports on Human Health Risks: 2014 Letter Report. This is the second of five Institute of Medicine reports to review more than 30 evidence reports that the National Aeronautics and Space Administration has compiled on human health risks for long-duration and exploration space flights. It builds on the 2008 IOM Review of NASA’s Human Research Program Evidence Books: A Letter Report, which provided an initial and brief review of the evidence reports. This review of seven evidence reports examines the quality of the evidence and analysis of each report, identifies gaps in report content, and suggests additional sources of expert input. The report analyzes each evidence report’s overall quality, including readability, internal consistency, source and breadth of cited evidence, identification of knowledge and research gaps, authorship expertise, and, if applicable, response to recommendations from the 2008 IOM report.

NAE member Laurence R. Young, Apollo Program Professor of Astronautics and professor of health sciences and technology, Massachusetts Institute of Technology, was a member of the study committee. Paper, $44.00.

Sharing the Adventure with the Student: Exploring the Intersections of NASA Space Science and Education—A Workshop Summary. In December 2014 the NRC Space Studies Board and Board on Science Education held a workshop, “Sharing the Adventure with the Student,” on the NASA Science Mission Directorate (SMD) education program. Representatives of the space science and science education communities discussed ways to maximize knowledge transfer from SMD-supported scientists both to K–12 students directly and to teachers and informal educators. The workshop not only explored effective models for transferring science content and scientific practices to students, but also served as a forum for dialogue among education specialists, education staff from NASA and other agencies, space scientists and engineers, and science content generators. This report is the summary of the workshop presentations and discussions.
NAE member Wesley L. Harris, Charles Stark Draper Professor of Aeronautics and Astronautics, Massachusetts Institute of Technology, was a member of the study committee. Paper, $44.00.

Sea Change: 2015–2025 Decadal Survey of Ocean Sciences. Ocean science involves an international community of scientists in many disciplines—physics, chemistry, biology, geology, and geophysics—and new observational and computational technologies are transforming their ability to study the global ocean with a more integrated and dynamic approach. Comprehensive understanding of the global ocean is needed for forecasting and managing risks from severe storms, adapting to the impacts of climate change, and managing ocean resources. In the United States the National Science Foundation (NSF) is the primary funder of the basic research that advances knowledge of the ocean. This report describes strategic NSF investments necessary to ensure a robust ocean science enterprise over the next decade, with guidance from the ocean sciences community on priorities for research, facilities, and funding.

NAE member Don Walsh, president, International Maritime Inc., was a member of the study committee. Paper, $44.00.

A Review of the Next Generation Air Transportation System: Implications and Importance of System Architecture. The goal of the Next Generation Air Transportation System (NextGen) is the transformation of the US national airspace system through programs and initiatives that could make it possible to shorten routes, navigate better around weather, save time and fuel, reduce delays, and improve capabilities for monitoring and managing of aircraft. This report reviews NextGen and examines the technical activities (e.g., human-system design and testing, organizational design, and other safety and human factor aspects) that will be necessary to successfully transition to the future system.

The report assesses technical, cost, and schedule risk for the software development that will be needed to achieve the expected benefits from a highly automated air traffic management system and the implications for ongoing modernization projects.

NAE members on the study committee were Steven M. Bellovin, professor, Department of Computer Science, Columbia University; R. John Hansman Jr., T. Wilson Professor of Aeronautics and Astronautics and director, MIT International Center for Air Transportation; Gavriel Salvendy, research professor, Louisiana State University, chair professor emeritus and former head, Industrial Engineering Department, Tsinghua University, Beijing, and professor emeritus, School of Industrial Engineering, Purdue University; Thomas B. Sheridan, Ford Professor of Engineering and Applied Psychology Emeritus, Massachusetts Institute of Technology; Robert F. Sproull, adjunct professor of computer science, University of Massachusetts, Amherst, and retired vice president and director, Oracle Labs; and Elaine Weyuker, independent software engineering researcher, Metuchen, New Jersey. Paper, $42.00.

Interim Report on 21st Century Cyber-Physical Systems Education. Cyber-physical systems (CPS) are smart, networked systems with embedded sensors, computer processors, and actuators that sense and interact with the physical world; support real-time, guaranteed performance; and are often found in critical applications. They increasingly provide functionality and value to products, systems, and infrastructure in sectors such as transportation, health care, manufacturing, and electrical power generation and distribution. But they also can create vulnerability in security and reliability. As CPS become more pervasive, so too will demand for a workforce with the capacity and capability to design, develop, and maintain them. Building on its CPS research program, the National Science Foundation (NSF) is exploring requirements for education and training and asked the NRC to study the topic. Two workshops in 2014 considered the knowledge and skills required for CPS work, education, and training requirements and possible approaches to retooling engineering and computer science programs and curricula to meet these needs. This report summarizes the workshop discussions.

NAE members on the study committee were Panganamala R. Kumar, College of Engineering Chair in Computer Engineering, Department of Electrical and Computer Engineering, Texas A&M University–College Station; Sanjoy K. Mitter, professor of electrical engineering, Massachusetts Institute of Technology; and José M.F. Moura, Philip and Marsha Dowd University Professor, Department of Electrical and Computer Engineering, Carnegie Mellon University. Paper, $38.00.

Industrialization of Biology: A Roadmap to Accelerate the Advanced Manufacturing of Chemicals. The past decade has witnessed major advances made
possible by biotechnology, and the manufacture of chemicals using biological synthesis and engineering could expand even faster. Achievement of the benefits of the industrialization of biology will depend on a proactive strategy, implemented through the development of a technical roadmap similar to those that enabled sustained growth in the semiconductor industry and explorations of space. This report presents such a roadmap. It examines the technical, economic, and societal factors that limit the adoption of bioprocessing in the chemical industry and that, if surmounted, would markedly accelerate the advanced manufacturing of chemicals via industrial biotechnology. The report articulates key technical goals for next-generation chemical manufacturing; identifies the knowledge, tools, techniques, and systems required to meet those goals; and sets targets and timelines for achieving them. The report also considers the skills necessary to accomplish the roadmap goals, and what training opportunities are required to produce the cadre of skilled scientists and engineers needed.

NAE member Jay D. Keasling, Hubbard Howe Jr. Distinguished Professor of Biochemical Engineering, University of California, Berkeley, was a member of the study committee. Paper, $60.00.

Diplomacy for the 21st Century: Embedding a Culture of Science and Technology Throughout the Department of State.

This report recommends steps for the Department of State to take advantage of US science and technology (S&T) capabilities in order to promote the interests and help ensure the international security of both the United States and its allies in a rapidly changing world. The report assesses the changing environment for diplomacy, with a focus on the role of S&T in the development and implementation of US policies and programs. It calls for prompt steps by the department's leadership to ensure adequate comprehension of the importance of S&T-related developments around the world and to incorporate this understanding in the country's foreign policy. It also urges the department's adoption of a whole-of-society approach in carrying out its responsibilities at home and abroad, extending beyond traditional interagency coordination and current external partners to include foundations, universities, research centers, and other groups with an international reach.

NAE member Glen T. Daigger, president, One Water Solutions, was a member of the study committee. Paper, $48.00.

Overcoming Barriers to Deployment of Plug-in Electric Vehicles.

Interest in plug-in electric vehicles (PEVs) has grown, thanks to their advantages over conventional vehicles—lower operating costs, smoother operation, and better acceleration; the ability to fuel up at home; and zero tailpipe emissions when the vehicle operates solely on its battery. But barriers to PEV use include vehicle cost, a short all-electric driving range, long battery charging time, uncertainties about battery life, limited choices of vehicle models, and the need for charging infrastructure. What should industry do to improve the performance of PEVs and make them more attractive to consumers? At the request of Congress, this report examines the characteristics and capabilities of electric vehicle technologies (e.g., cost, performance, range, safety, and durability), assesses how these factors might create barriers to widespread deployment, and—based on consideration of consumer behaviors, tax incentives, business models, incentive programs, and infrastructure needs—presents recommendations to further the development and acceptance of the industry.

NAE members on the study committee were John G. Kassakian (chair), professor of electrical engineering and computer science, Massachusetts Institute of Technology; Linos J. Jacovides, professor, Electrical and Computer Engineering Department, Michigan State University, and retired director, Delphi Research Labs; and Ralph D. Masiello, senior vice president, innovation, DNV GL. Paper, $59.00.
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Donor Spotlight

GEORGE BUGLIARELLO (’87) and his widow, VIRGINIA, have always valued education. George, who died in 2011, spent most of his long and distinguished career in academia, first as dean of engineering at the University of Illinois at Chicago and then as president and chancellor of Polytechnic Institute of New York University. And Virginia, who recently retired after serving 40 years as a librarian at the Port Washington, NY, public library, is a committed volunteer for an adult literacy program.

So it seemed fitting to Virginia to honor George’s memory by making a generous gift to the National Academy of Engineering’s EngineerGirl program, dedicated to encouraging girls and young women to become engineers.

“In the early ’70s, George organized a symposium when he was at the University of Illinois that was one of the first efforts in encouraging women to go into engineering,” Virginia said. “This gift to EngineerGirl felt perfect.”

The gift also recognizes George’s decades of service to the NAE. He was NAE foreign secretary from 2003 to 2011, “interim” editor of the Bridge for more than 10 years, and a member of dozens of committees. Virginia says, “He was always involved because the NAE meant a lot to him. And by osmosis, it means a lot to me.”

For additional information or to make a gift, please contact Radka Nebesky at 202.334.3417 or RNebesky@nae.edu.