The intellectual leadership role that the engineering profession must play in reindustrializing America.

By N.J. Slabbert

ENGINEERS

A provocative reflection on the intellectual position of engineers and engineering in the United States is that, according to the office of Ted Kaufman, he is currently the only engineer in the U.S. Senate. One engineer in a hundred of America's most powerful policymakers seems pretty impressive. Or is it? A 2007 count by *The Wall Street Journal* found sixty lawyers in the Senate. This professional ratio casts a sobering light on the status and influence of engineers in American society.

The U.S. Bureau of Labor Statistics expects mechanical engineering to experience employment growth of 6 percent over the decade leading up to 2018—a rate slower than the average for all occupations. (Over the same period lawyers are expected to increase 13 percent, physicians 22 percent, and athletic coaches and scouts 25 percent.) A 2007 survey on engineering employment, initiated by the Corporate Partnership Council of the Society of Women Engineers and analyzed with the help of the Commission on Professionals in Science and Technology, found that many engineers were not profoundly satisfied in their work. More telling than this general conclusion, though, was the determination that of male engineers who left engineering to find a job in another field, 16 percent did so to earn more money, whereas 32 percent changed careers to find more interesting work. For female engineers who switched careers, the difference between financial motivation and the quest for more intellectual satisfaction was even greater: 4 percent versus 48 percent.

These figures are highly relevant for anyone who is concerned about the future of engineering. They call for a reassessment of our ideas of what engineering is, how it relates to the rest of society, including other disciplines, and how different kinds of engineering relate to each other. The timeliness of such a reassessment became clear to me in 2008 when I began collaborating with one of the U.S.'s most distinguished technological leaders on research about the need to re-energize America's economy through a fresh wave of techno-

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AS VISIONARIES

logical development. An initial 2009 book reflecting this research, *Innovation, The Key to Prosperity: Technology & America's Role in the 21st Century Global Economy* (introduced by former National Science Foundation head Rita Colwell), surveyed technological industrialization from two perspectives.

One perspective was an intimate view from deep inside America's technological leadership community, with an emphasis on engineering. My collaborator, Aris Melissaratos—currently senior advisor on technology enterprise to the president of Johns Hopkins University—is an engineer who worked for over 30 years in the Westinghouse group, where he was responsible for 16,000 employees and some $3.2 billion in annual revenues. His positions included chief technology officer, vice president for science and technology, and chief operations officer. He also founded Armel Scientifics, an investor in over 30 start-up companies in advanced technology. Before joining Johns Hopkins he served as business and economic development secretary of the state of Maryland.

The second perspective of the research collaboration was the larger context of the evolution of technology and science. That was the professional angle that I brought to our survey. At first glance these two perspectives seem to have little in common: one flows from the hands-on, applied work of a highly accomplished technological practitioner, the other from a philosophical, cultural, and historical review of the technological professions. But my engineer colleague and I found that our conclusions about America's 21st century technological challenges and opportunities converged powerfully.

We agreed that America's economic achievements in the 20th century rested strongly on industrialization driven by technological innovation, that innovation had ebbed in the century's second half, that a renewal of a national sense of innovative purpose was needed to launch a new industrial era, that this task required a revival of industrialization through national infrastructure-building projects—the "reengineering of America"—and that the nation urgently needed to place a higher value on STEM subjects (science, technology, engineering, and mathematics).

Illusions of Progress

In terms of technological innovation and industrial creativity, the United States is not today the country it once was. In the second half of the 20th century this ebb was masked by several phenomena. An illusion of sustained innovative momentum was created by the vigorously continuing exploitation of legacy technologies, including obsolete energy sourcing. Wall Street activities increased in intensity even as they became more tenuously associated with industrial productivity and innovation. Computerization, although based on innovations dating back decades, was exploited with such media panache that it fostered a misleading impression of technological growth across the board. In fact, the nation entered an era of deindustrialization in the second half of the 20th century.

In June 1980 *Business Week* reported: "The U.S. economy must undergo a fundamental change if it is to retain a measure of economic viability let alone leadership in the remaining 20 years of this century. The goal must be nothing less than the reindustrialization of America." But this was not achieved (and, one might argue, not even forcefully pursued as a concerted national aim). As a result, America reached the 21st century severely challenged in STEM education and by environmental, energy, and economic sustainability problems linked to insufficient technological innovation.

Examples of this insufficiency include the government bailout of an automobile industry that relied too long on cosmetic innovation rather than on real technological improvement, and the collapse of venerable financial giants whose idea of wealth creation was excessively focused on paper wealth to the detriment of industrial productivity.

If America has lost its technological and industrial compass, it is strongly arguable that engineering is better equipped than most other professions to correct it by helping the nation build a new vision of its technological future. The reindustrialization of America on a massive scale is now needed more urgently than ever, and engineers have a pivotal role to play in it: not only in its implementation but in motivating the American public

and its policymakers to pursue reindustrialization and technological innovation as a national goal.

Engineers must move into a central place in the nation's intellectual life, rather than occupying a technical advisory role on the side. If they achieve this, a new golden age of industrial productivity may yet await America in the 21st century, with engineers in the forefront of the visionaries who lead it. But does the professional self-image and sense of mission of engineering currently encourage or even allow such a visionary function? Answering this question requires engineers to reexamine the philosophy, intellectual evolution, and purpose of their profession.

▶ **Mathematician was one of many roles of influence played by Charles Babbage, who held Newton's former professorship at Cambridge.**

The statistics about the engineering profession referenced above suggest an unease about a contemporary engineer's role in society. This feeling is reflected by the interdisciplinary politics to be found, for instance, in the writings of engineer Henry Petroski. He is indignant that science and scientists appear to have earned a position in society that unfairly eclipses the status accorded to engineers. In *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems* (2010) and other works, Petroski positions engineering ingenuity as something different from science and capable of contributions that science *per se* cannot match.

Petroski's work is useful and stimulating but tends to obscure the intimate transdisciplinary connections between scientific problem-solving and engineering problem-solving that have shaped technological progress. These two kinds of problem-solving are not really separate. They have often been pursued creatively by single individuals working on single projects. Viewed against this background, complaints like Petroski's don't just identify a major challenge confronting contemporary engineers; they are also symptomatic of that challenge, which can be broadly defined as the isolation of engineering from national intellectual life, from the sense of national purpose, and from the center of public policymaking.

The words "interdisciplinary" and "transdisciplinary" here are significant. The way engineers see their discipline arguably has much to do with engineering's past and present potential to provide society with large-scale visions that go beyond the confines of engineering. Consider, for example, Charles Babbage. In 1830 he published a treatise in London called *Reflections on the Decline of Science in England*. He was then Lucasian Professor of Mathematics at Cambridge University—a position formerly held by physicist Isaac Newton and today occupied by scientist Stephen Hawking.

Babbage is one of many engineers of the past whose accomplishments and philosophies have much to teach both the public and the engineering profession about innovation leadership and the role of the engineering profession in the 21st century. This is so for at least two reasons. One is Babbage's great intellectual range. He was a gifted, creative mathematician, a highly inventive engineer and computer pioneer, a social reformer, a philosopher, an economist, an author of books of graceful prose ranging from autobiography to taxation, and even a theologian. Second, he was a visionary.

Babbage's milieu predated the rise of narrow professional specialization in the form in which we now know it. While practicing engineers today have little time to concern themselves much with their profession's history, those who do study it know that the borders of the engineer's intellectual world weren't always where they presently are. Just as geopolitical maps are periodically redrawn to reflect changes in governmental jurisdictions, the landscape of disciplinary politics, too, evolves over time. New professional fiefdoms arise and old ones pass away. So it has been with engineering, which once overlapped other fields of expertise to make polymaths like Babbage possible.

This changed as greater professionalization of expertise in the 19th and early 20th centuries was driven by various forces, including strong economic ones. By creating professional societies that controlled the certification and accreditation of experts in engineering and many other fields, knowledge workers gained economic advantages. They acquired more prestige, enhanced the mystique of their discipline by closing it to outsiders, improved the marketing and pricing of their services, and managed the politically valuable recognition of their members by government.

But these new privileges weren't cost-free. They were traded for others, such as the transdisciplinary flexibility in which people like Babbage excelled. Intellectual activity across a broad spectrum of arts, crafts, or bodies of learning is popularly associated with a handful of conspicuous figures like Leonardo da Vinci, but engineers and other experts ranged quite freely across multiple fields of expertise for centuries until 20th century specialization curtailed their scope.

Seeing What Lies Beyond

Of course, really creative thought spanning several disciplines requires special gifts. But it's equally true that polymathy was especially encouraged by more loosely professionalized cultures. This brings us to Babbage's status as a visionary and what it has to teach 21st century engineers.

The willingness of engineers, scientists, and other experts of Babbage's day to think in visionary terms was closely related to their transdisciplinary freedom. The word "visionary" has many interpretations, but the most widely accepted ones tend to share the idea that visionaries transcend the limits of conventional systems of knowledge. They draw conclusions, form conjectures, and posit outcomes and possibilities beyond those which are strictly justified by the conventions of this or that discipline.

Hence the association with the word "vision": whereas most experts work out conclusions using their discipline's established protocols, visionaries form some of their conclusions by apparently just "seeing" them. They look, as it were, over their discipline's fences and make connections between their field and the wider world beyond. These perceptions can then be developed into large-scale statements of philosophical purpose to guide society.

Consistently with these visual analogies, visionaries are sometimes also called "far-sighted." Many (perhaps most) results of such visionary exercises are worthless. But the fruitful ones can help shape civilizations.

Babbage was a visionary in this sense. His book on the deterioration of science in England took a large-scale view of the condition of all kinds of scientific work in his country. It looked to the past and to the future. It was informed by deep personal concern for the progress of the sciences in general and by insight into many corners of practical scientific governance.

Babbage sought to give science a more central place in British life and to involve the general public and the government more actively in scientific projects. His efforts contributed significantly to the English intelligentsia's critical reassessment of its scientific community. One result was the establishment of Britain's Association for the Advancement of Science (now the British Science Association). Another was a new effort to define Britain as a global leader in scientific and technological progress. This movement led to the organizing of London's Great Exhibition of 1851, a huge fair which both expressed and influenced Britain's aggressive positioning of itself as a driver of a new technological era.

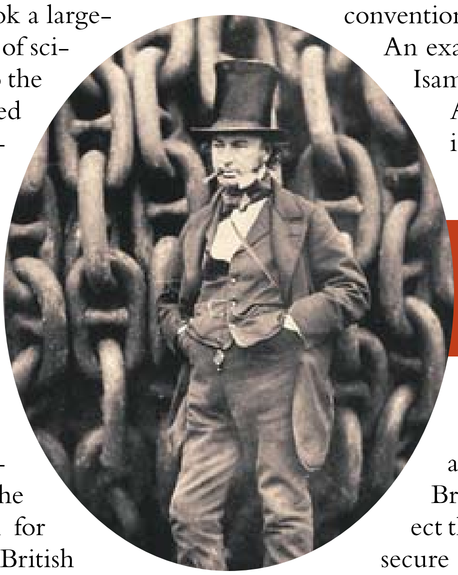
The exhibition was aggressively championed by the Crown in the person of Queen Victoria's husband, Prince Albert, who was hugely excited by the movement to make Britain a world science leader. His actions on its behalf included a term as president of the Association for the Advancement of Science.

Babbage was a visionary in other areas as well. His pioneering work to design and build a machine that would mimic the calculating processes of the human mind was an important step in the development of computers. His dogged persistence with this vision, amid failures that eventually lost him his funding, brought him to the end of his life as a bitter man. This isolation, too, makes him a good representative of visionaries, who are often set apart by long and stubborn adherence to a belief in something that they see as not only feasible but even perhaps inevitable despite the skepticism of others.

Engineering history is rich in visionaries like Babbage whose reach exceeded their grasp. Part of the reason for this goes to the nature of engineering, in which it is possible to hit on an excellent idea which is nevertheless ahead of its time because the tools needed to realize it don't yet exist. Sometimes promoting the idea energetically can help develop the missing technology, but this doesn't always happen in the visionary's lifetime. Such individuals may end up feeling frustrated by the tools and imaginations of their time.

However, visionaries have by no means been only brilliant, inspiring failures. Some have been innovators whose combination of ingenuity, determination, ego, and counterintuitive ambitions have, within their lifetimes, enabled them to accomplish things that more conventional or complacent minds did not dare. An example is 19th century British engineer Isambard Kingdom Brunel.

A man of remarkable talents, including indomitable will and stamina, Brunel died at 53, having worked himself to death. He achieved what most people would need several lifetimes to approach. He and his father, Sir Marc Brunel, collaborated on a grueling project that seemed unrealistic—creating a safe, secure walkway beneath the river Thames. Using 19th century technology they not only accomplished it but did it so well that it was later incorporated into the London subway system and remains in use in the 21st century.



◀ Isambard Kingdom Brunel, a hands-on Victorian Era engineer, rolled back the boundaries of what was thought possible.

Isambard went on to shape his era with a series of projects from railway system development and bridge design to steamships. He is important not only for the individual artifacts he designed and built but, even more so, for the new mental horizons he opened up. His work (like the biggest ship ever built up to that time, which introduced the revolution of propeller power) rolled back the boundaries of what had been thought possible. He brought engineers of his age a sense of technological optimism and large-scale project feasibility that Americans today, contending with a decaying national infrastructure and a NASA facing increasing funding cuts, can scarcely appreciate.

Babbage and Brunel represent two different kinds of engineering visionaries. In addition to having a precise grasp of mathematically computed realities, Babbage was a prolific writer who communicated his social and philosophical ideas in eloquent literary form. Brunel was a doer who expressed himself through his applied projects.

Both, however, were large-scale thinkers out not merely to respond to market demand or client instruction but to change their world proactively. Both possessed deep-seated optimism about human capability that defied conventional beliefs about what was possible. Both respected expertise but ignored its conventional boundaries when these impeded their pursuit of visions that seemed to them to make sense.

The Biggest Engineering Feat

This blend of transdisciplinary imagination, technological optimism, and determination to change the world by invention is today unusual in American culture. It flourished in the late 19th and early 20th centuries. It characterized the Chicago World's Fair of 1893, a counterpart of the British Great Exhibition, as well as the 20th century rise of fields like nuclear physics and genetics.

This same period was a golden age for engineers. Economic growth and the sense of national identity seemed inseparable from the large-scale exercise of engineering ability. The infrastructure America built during this era—encompassing railways, highways, electrification, high-rise skylines, airlines, telecommunications, and all the industries serving these systems—forms, in a sense, a single vast artifact: the biggest engineering feat in history. Yet even during those amazing decades the seeds of a very different era were being sown, in which technological inventiveness would increasingly take a back seat to a different idea: that of management expertise as somehow making the need for technological drive and engineering inventiveness redundant.

▶ **The spirit evident in 1893 at the Chicago World's Fair and in early 20th century innovations is less common today.**

This current in American intellectual history was extremely important but very subtle and complex. It was not a case of engineers being physically replaced by non-engineering managers; rather, engineers themselves helped create a new concept of management expertise which in turn came to overshadow the value of technological inventiveness.

Innovation and indeed even engineering tended to be seen as subdivisions of management expertise. This trend gave birth to a fashionable management consulting industry, including a new breed of best-selling professors.

Peter F. Drucker, a non-engineer, came to wield immense influence in the business world. He saw industrial development as revolving around corporate credos and human relations. The way for Drucker's career emergence in the 1940s and 1950s had been paved by an intellectual climate that included the Efficiency and Technocracy Movements, both of which valued the reconfiguring of existing economic resources by social policy and philosophical belief, rather than the creation of new resources by industrial innovation.

The Efficiency Movement was an approach to industrial methodology that strongly encouraged specialization as well as the idea that specialists could function best under the guidance of a new, superior kind of specialist, the efficiency expert or management expert. The Technocracy Movement, on the other hand, was not a methodological philosophy but a political one. Its central concept was that society's problems could be best solved by putting scientists and engineers (i.e., specialists) in charge.

Despite the high status that this notion seemed to accord to scientists and engineers, Technocracy—like the Efficiency Movement—held that these ruling experts should not be "ordinary" scientists and engineers but ones who shared the movement's special philosophy of management. Both movements believed that industrial progress could be turned into a kind of social science. This idea of innovative progress was legalistic, assuming that industry is like a court of law, where orderly process according to well-articulated rules is of high, and possibly the highest, value.

The origins of this legalistic approach is visible in several historical strands. Drucker's doctorate was in law. One of the most influential representatives of the Efficiency Movement, Frederick W. Taylor, was a mechanical engineer who initially planned to study law. It has been argued that the first person who spoke of scientific management in its fully defined modern sense was the lawyer (and later Supreme Court Justice) Louis D. Brandeis.

But while a legalistic interpretation of industrial process may have some merit, it is very limited. Courts create a valuable social product in the form of opinions, but industrial progress depends on a different kind of inventiveness. When legalistic theory operates in isolation from real engineering inventiveness and vision, the results can be sterile and disastrous. It is thought-provoking that Herbert Hoover, U.S. president from 1929 to 1933, was a supporter of the Efficiency Movement, and that the Soviet leader Vladimir Lenin was greatly attracted by F.W. Taylor's ideas.

Although this intellectual background sounds very abstract, it is an important part of the cultural pattern that underlies the situation of engineering today. While extremely valuable management theory exists, it is time to ask whether the successful marketing of management theory in the intellectual marketplace, as a charismatic and even popularly entertaining custodian of innovation techniques, has been as helpful as it might be to the development of engineering as an intellectual contributor to society.

It is also important to ask questions about other historical forces that have shaped engineering and are continuing to influence it. One is the increasing specialization of engineering. As management theory expanded to become a prestigious academic domain with lucrative consulting activities and wide appeal to the general public, often via popular media exposure offering the transdisciplinary flavor that engineering had formerly possessed, so engineers tended to retreat from public conversation.

Another element in this tapestry of intellectual change was the attitude of American culture toward technology. By the mid-20th century, in a world gripped by the Cold War and the fear of nuclear destruction, many people were associating science and technology with a sinister military-industrial complex and with environmental destruction. Others saw the active encouragement of scientific and technological innovation as a betrayal of free market principles; they believed it was patriotic to think of American innovation as automatic. Both tendencies contributed to a national failure to promote ongoing scientific and technological innovation.

Reviving Expectations

As a result of all of these intellectual currents, America is today paying the price of deindustrialization. While there is no single answer to this problem, it is safe to say that all useful answers are likely to relate strongly to the determination and capability with which America promotes scientific advance and technological innovation. This will necessarily entail a reassessment of what society can and should reasonably expect from engineers.

Such discussion cannot be conducted meaningfully without considering the historical evidence that engineers once served their societies as thought leaders of a transdisciplinary, visionary kind that they no longer seem to be, regardless of their many other merits as a profession. Reclaiming some degree of this earlier role, in a form suited to the needs of the 21st century, can only be good for society and engineers alike. ■

Declines of Science

CALLS TO ELEVATE STUDIES OF SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS IN U.S. SCHOOLS HAVE BEEN MADE FOR YEARS. Judging by the general public's level of technical and scientific literacy, it is clear that making such a call has not done enough.

Many of the scientific disciplines that the STEM subjects represent have undergone drastic change.

Nuclear physics, for instance, once a field whose immense mystique was reinforced by such charismatic figures as Einstein, became increasingly associated with weapons and other controversial subjects from the 1940s through the rest of the 20th century, to the extent that by late century nuclear scientists were conferring to see what could be done to repair their tarnished public image. This is one of intellectual history's most extraordinary marketing disasters.

Astronomy also has changed significantly since the 19th century in ways which, in part, parallel the evolution of engineering.

Early 20th century astronomers like Sir James Jeans and Sir Arthur Eddington were encyclopedic intellectuals. They published, for example, books of serious philosophy. Astronomy thereafter evolved into quite a different thing, forfeiting much of its philosophical voice in a chase after funding (from government and the entertainment industry) which has added little to the discipline's real public appeal. Despite media phenomena like Carl Sagan and *Star Trek*, the National Optical Astronomy Observatory reports that by 2009 America faced a severe shortage of jobs for astronomers that is not expected to get better soon.

Pathetically, in 2001 America's National Academy of Sciences advertised to young people the dubious incentive that an astrophysical degree might qualify them for jobs as movie special-effects advisers.

It is therefore unsurprising that perceptions of engineers, both within and outside the engineering community, have not stood still. It would be useful for engineers to reflect on this and consider whether all the changes have been positive.