A Flexner Report for Engineering: The Future of Engineering Practice, Research, and Education

James J. Duderstadt

2016 Ralph Coats Roe Lecture
American Society of Mechanical Engineering
June 6, 2016

An array of powerful forces, including changing demographics, globalization, and rapidly evolving technologies, is driving profound changes in the role of engineering in society. The growing awareness of the importance of technological innovation to economic competitiveness and national security is demanding a new priority for the engineering profession. The exponential evolution of technologies such as computers and gene manipulation and the nonlinear nature of the flow of knowledge between fundamental research and engineering application demand new paradigms in engineering research and development. The changing technology needs of a global knowledge economy are challenging the nature of engineering practice, demanding far broader skills than simply the mastery of scientific and technological disciplines.

The fundamental knowledge undergirding engineering practice increasingly requires research at the extremes, from the microscopic level of nanotechnology and gene manipulation to the mega level of global systems such as civil infrastructure, energy, and climate change, as well as the mastery of new tools such as quantum engineering and data-intensive computing. It also requires far greater attention by government and industry to the support of the long-term research necessary to sustain an engineering knowledge base key to addressing society's needs.

Moreover, challenges such as the off shoring of engineering jobs, the decline of student interest in scientific and engineering careers, immigration restrictions, and inadequate social diversity in the domestic engineering workforce, are also raising serious questions about the adequacy of our current national approach to engineering education.

A Flexner Report for Engineering?

Over the years there have been numerous studies by organizations such as the

National Academies, federal agencies, business organizations, and professional societies suggesting the need for new paradigms in engineering practice, research, and education that better address the needs of a 21st-century global, knowledge-driven society. In a sense, the challenge faced by engineering today is similar to that characterizing medical practice a century ago. During the 19th-century, medical education had evolved from a practice-based apprenticeship to dependence primarily upon didactic education (a year of lectures followed by a licensing exam), losing the rigor of training critical to competent health care. Many students had less than a high school education and none required a college degree. The Carnegie Foundation for the Advancement of Teaching commissioned noted educator Abraham Flexner to survey 150 medical schools over a yearlong period and draft a report concerning the changing nature of the profession and the implications for medical education. As Flexner observed in his report of 1910, medical education was a farce as it was taught in most schools, "without laboratories, without trained and salaried men, without dispensaries, and without hospitals". The Flexner Report transformed medical education and practice into the 20th century paradigm of scientific (laboratory-based) medicine and clinical training in teaching hospitals (Flexner, 1910). The key to the impact of the report was to promote educational reform as a public health obligation: "If the sick are to reap the full benefit of recent progress in medicine, a more uniformly arduous and expensive medical education is demanded." Key would be the requirement that all physicians should be well-educated, highly trained diagnosticians and problem solvers who understand the laboratory basis for scientific knowledge and have become skilled through extensive clinical experience. A medical degree would require a four-year post-undergraduate program based on inductive teaching in medicine and science–learning by doing–in a university setting that joined investigative science to practical training.

Here it is interesting to note that during his study of medicine, Flexner raised very similar concerns about engineering education even at this early period. "The minimum basis upon which a good school of engineering accepts students is, once more, an actual high school education, and the movement toward elongating the technical course to five years confesses the urgent need of something more." During the past century there have been numerous efforts to conduct an analysis of engineering very similar in spirit to the Flexner Report. As Bill Schowalter, former Dean of Engineering at the University of Illinois observed, "The appearance every decade of a definitive report on the future of engineering education is as predictable as a sighting of the first crocuses in spring" (Schowalter, 2003). Yet throughout the past century, engineering education has remained remarkably stable–to be sure, adding more scientific content, but doing so within a four-year undergraduate program based primarily upon scientific problem solving and resisting most efforts to elevate it to the post-graduate practice-based programs characterizing other learned professions such as medicine and law.

Ironically, although engineering is one of the professions most responsible for and responsive to the profound changes in our society driven by evolving technology, its characteristics in practice, research, and education have been remarkably constant–some might even suggest stagnant–relative to other professions. Several years ago I joined with several colleagues in a National Science Foundation project aimed as drafting a "Flexner Report" for engineering, first assessing the character and challenges of contemporary engineering practice, research, and education, and then developing a series of recommendations and actions aimed at transforming engineering with the fundamental objective of sustaining and enhancing our nation's capacity for the technology innovation key to economic prosperity, national security, and social well being.

So what should our nation seek as both the nature and objectives of engineering in the 21st century, recognizing that these must change significantly to address rapidly changing needs and priorities? Here we need to consider the implications for American engineering from several perspectives: i) as a *discipline* (similar to physics or mathematics), possibly taking its place among the "liberal arts" characterizing a 21st-century technology-driven society; ii) as a *profession,* addressing both the urgent needs and grand challenges facing our society; iii) as a *knowledge base* supporting innovation, entrepreneurship, and value creation in a knowledge economy; and iv) as a diverse *educational system* characterized by the quality, rigor, and diversity necessary to produce the engineers and engineering research critical to prosperity, security, and social well being.

Here we began with several premises:

- In a global, knowledge-driven economy, technological innovation–the transformation of knowledge into products, processes, and services–is critical to competitiveness, long-term productivity growth, and the generation of wealth. Preeminence in technological innovation requires leadership in all aspects of engineering: engineering research to bridge scientific discovery and practical applications; engineering education to give engineers and technologists the skills to create and exploit knowledge and technological innovation; and the engineering profession and practice to translate knowledge into innovative, competitive products and services.

- To compete with talented engineers in other nations with far greater numbers and with far lower wage structures, American engineers must be able to add significantly more value than their counterparts abroad through their greater intellectual span, their capacity to innovate, their entrepreneurial zeal, and their ability to address the grand challenges facing our world.

- It is similarly essential to elevate the status of the engineering profession, providing it with the prestige and influence to play the role it must in an increasingly technology-driven world while creating sufficiently flexible and satisfying career paths to attract a diverse population of outstanding students. Of particular importance is greatly enhancing the role of engineers both in influencing policy and popular perceptions and as participants in leadership roles in government and business.

- From this perspective the key to producing such world-class engineers is to take advantage of the fact that the comprehensive nature of American universities provide the opportunity for significantly broadening the educational experience of engineering students, provided that engineering schools, accreditation agencies such as ABET, the profession, and the marketplace are willing to embrace such an objective. Essentially all other learned professions have long ago moved in this direction (law, medicine, business, architecture), requiring a broad liberal arts baccalaureate education as a prerequisite for professional education at the graduate level.

In summary, we believed that to meet the needs of the nation, the engineering profession must achieve the status and influence of other learned professions such as law and medicine. Engineering practice in our rapidly changing world will require an ever-expanding knowledge base requiring new paradigms for engineering research that better link scientific discovery with innovation. The complex challenges facing our nation will require American engineers with a much higher level of education, particularly in professional skills such as innovation, entrepreneurship, and global engineering practice. To this end, we set the following objectives for engineering practice, research, and education:

1. To establish engineering practice as a true learned profession, similar in rigor, intellectual breadth, preparation, stature, and influence to law and medicine, with extensive post-graduate education and a culture more characteristic of professional guilds than corporate employees.

2. To redefine the nature of basic and applied engineering research, developing new research paradigms that better address compelling social priorities than those methods characterizing scientific research.

3. To adopt a systemic, research-based approach to innovation and continuous improvement of engineering education, recognizing the importance of diverse approaches–albeit characterized by quality and rigor–to serve the highly diverse technology needs of our society.

4. To establish engineering as a true liberal arts discipline, similar to the natural sciences, social sciences, and humanities, by imbedding it in the general education requirements of a college graduate for an increasingly technology-driven and -dependent society of the century ahead.

Of course, the efforts at developing and implementing a Flexner approach to engineering joined those of many predecessors and colleagues among Schowalter's spring crocuses. Yet, there were some minor successes: one in engineering research, one in engineering education, and one in the nature of the engineering profession

A New Paradigm for Engineering Research

In 2005, the U.S. National Academies issued a series of reports suggesting that a bold, transformative initiative, similar in character and scope to initiatives undertaken in response to other difficult challenges (e.g., the Land Grant Acts, the G.I. Bill, and the post-WWII government-university research partnerships) will be necessary for the United States to maintain its leadership in technological innovation (Augustine, 2005). The United States will have to reshape its research, education, and practices to respond to challenges in global markets, national security, energy sustainability, and public health. The changes envisioned were not only technological, but also cultural; they would affect the structure of organizations and relationships between institutional sectors of the country.

To this end, it was the recommendation of the U.S. National Academy of Engineering that a major federal initiative be launched to create translational research organizations aimed at building the knowledge base necessary for technological innovation in areas of major national priority (Duderstadt, 2005). These organizations, referred to as discovery-innovation institutes and later as innovation hubs, would be established through a new type of partnership among universities, federal research laboratories, and industry to link fundamental scientific discoveries with technological innovations to create products, processes, and services to meet the needs of society. The federal government would provide both core support and the participation of national laboratories both in research and project management. Universities would provide both basic research and the education of research engineers in key areas. Industry would provide challenging research problems, systems knowledge, and real-life market knowledge, as well as staff who would work with university faculty and students. These discovery-innovation hubs would be similar in character and scale to academic medical centers and agricultural experiment stations in the manner in which they would combine research, education, and professional practice and drive transformative change.

In May 2009, the U.S. Department of Energy announced the first step of building just such research networks by launching an initial set of energy innovation hubs (referred to as “Bell lablettes” by Steve Chu, then Secretary of Energy) in areas of key energy challenges. In the spirit of the discovery-innovation institute concept the energy innovation hubs bring together teams of top scientists and engineers from academia, industry, and government to collaborate and overcome critical known barriers to achieving national climate and energy goals that have proven resistant to solution via the normal R&D enterprise. They focus on a single topic, with the objective of rapidly bridging the gaps between basic research, engineering development, and commercialization through a close partnership with industry. To achieve this goal, the hubs necessarily consist of large, highly integrated and collaborative creative teams working to solve priority technology challenges that require the sophisticated project management capabilities of both federal laboratories and industry.

As an example, the first energy innovation hub was CASL, the Consortium for Advanced Simulation of Light Water Reactors (CASL), with a focus on innovation in the modeling and simulation critical for commercial nuclear power commercial nuclear power development. CASL’s mission is to recapture the benefits of leadership in nuclear technology by providing coupled, high fidelity, usable analytic tools based on advanced supercomputer capabilities needed to address both light water reactor (LWR) and small modular reactor operational and safety performance-defining phenomena. CASL's unique partnership of government, academia, and industry possesses unparalleled collective institutional knowledge, nuclear science and engineering talent, computational science leadership, and LWR design and regulatory accomplishments. CASL has several key elements: clear deliverables and products that solve industry issues and are driven by a well-defined yet dynamic plan for executing on deliverables; a strategy of delivering prototype products early and often; a lead institution (Oak Ridge National Laboratory) with resource allocation authority and large scale project management experience.

During its first several years CASL has already been remarkably successful in developing new simulation tools such as VERA, a Virtual Environment for Reactor Analysis, based on state-of-the-art supercomputers such as Titan and soon Summit at ORNL. These simulations have achieved dramatic advances in the ability to enhance the economic performance and safety of existing nuclear power plants and will serve as important design tools for future generations of nuclear systems.

Engineering as a "liberal art" for the 21st Century

One of the important challenges to engineering educators is to design their educational programs not as preparation for a particular disciplinary career but rather as the foundation for a lifetime of continuous learning. Put another way, the stress must shift from the mastery of knowledge content to a mastery of the learning process itself through what universities have long referred to as a "liberal education". While most professional education occurs at the graduate level, based upon a broad "liberal education" at the undergraduate level, engineering stands apart in its attempt to base professional practice upon a highly technical undergraduate curriculum. In view of the changes occurring in engineering practice and research, it is easy to understand why some raise concerns that we are attempting to education 21st century engineers with a 20th century curriculum taught in 19th century institutions.

Today there are increasing suggestions that professional engineering education should be taught at the graduate level (perhaps by "professors of practice" in engineering) based upon a much better integration of engineering education at the undergraduate level with the liberal arts. While some universities such as Dartmouth and Stanford offer dual degree programs with such goals, there has been increasing interest both within the National Academy of Engineering and the National Science Foundation in creating B.A. programs in liberal studies in engineering (Bucciarelli). As

Pister and King observe, "the essential confining problem is the fact that the United states continue to place the professional degree in engineering at the bachelor's level, so that intellectual breadth is squeezed out by the constraints of a four-year degree", not to mention the curriculum demands of ABET accreditation. (Pister, 2015) In fact, much of the rest of the world has already placed the professional degree at the graduate level, for example, the Chartered Engineering professional degree in the United Kingdom or the recognition that engineering should be at the masters level in the Bologna Process standardizing university education across Europe.

Beyond broadening engineering education to better prepare graduates for lifelong professional practice in a world of constant change, there are also major efforts underway to provide the fundamental concepts of engineering to students in other areas of study. Here William Wulf, former President of the National Academy of Engineering, warns that today we have a society profoundly dependent upon technology, profoundly dependent on engineers who produce that technology, and profoundly ignorant of technology. As Wulf observes, "I see this up close and personal almost every day. I deal with members of our government who are very smart, but who don't even understand when they need to ask questions about the impact of science and technology on public policy" (Wulf, 2003). He goes on to suggest that the concept of a liberal education for 21st-century society must include technological literacy as a component. Here he contrasts technological literacy with scientific and quantitative literacy, noting that everyone needs to know something about the process by which the knowledge of science is used to find solutions to human problems. But everyone also needs an understanding of the larger innovation engine that applies technology to create the wealth from which everyone benefits.

From this perspective, one could make a strong case that today engineering–or better yet technology–should be added to the set of liberal arts disciplines, much as the natural sciences were added a century ago. Here we are not referring to the foundation of science, mathematics, and engineering sciences for the engineering disciplines, but rather those unique tools that engineers master to develop and apply technology to serve society, e.g., structured problem solving, synthesis and design, innovation and entrepreneurship, technology development and management, risk-benefit analysis, and knowledge integration across horizontal and vertical intellectual spans.

To this end, in 2016 the National Academies of Science, Engineering, and Medicine have launched a major new study concerning "The Integration of STEM, Humanities, and the Arts". The goal of the study is to examine the evidence behind the assertion that educational programs that mutually integrate learning experiences in the humanities and STEM lead to improved educational and career outcomes for both undergraduate and graduate students, with the specific tasks of investigating:

i) the value of incorporating more STEM curricula and labs into academic programs of students majoring in the humanities and arts, preparing graduates for citizenship in an increasingly technology driven world, helping them to make sound decisions across all professional fields, and developing skills of scientific thinking, innovation, and creativity that can enrich their own fields of interest.

ii) the value of incorporating curricula and experiences in the humanities, including the arts, history, literature, philosophy, culture, and religion, into STEM education programs prepare STEM students to be more effective communicators, critical thinkers, problem-solvers, and leaders, while being more creative and effective scientists, engineers, technologists, and health care providers.

A Renaissance in Engineering Practice

The professions that have dominated the late 20th Century—and to some degree, the late 20th Century university—have been those which manipulate and rearrange knowledge and wealth rather than create it; professions such as law, business, accounting, and politics. Yet it is becoming increasingly clear that the driving intellectual activity of the 21st Century will be the act of creation itself, as suggested by Jacques Attali in his provocative forecasts for the 21st century at the turn of the Millennium:

> "The winners of this new era will be creators, and it is to them that power and wealth will flow. The need to shape, to invent, and to create will blur the border between production and consumption. Creation will not be a form of consumption anymore, but will become work itself, work that will be rewarded handsomely. The creator who turns dreams into reality will be considered as workers who deserve prestige and society's gratitude and remuneration."
> (Jacques Attali, 2000)

But today the new tools of creativity are appearing characterized by extraordinary power. We have the capacity to create new objects literally atom by atom.

With new methods in molecular biology such as CRISPR/Cas9 and gene drive, we can not only precisely modify the DNA code for a living organism, but actually cause it to propagate through a species to change future generations (a frightening thought when human gene editing is considered). The dramatic pace of evolution of information technology shows no sign of slowing, continuing to advance in power from 100 to 1000 fold a decade, enabling not only new forms of analysis such as augmenting the traditional tools of experiment and theory with the sophisticated tools of data analysis (big data). Indeed, the tools of artificial intelligence not only are rapidly progressing but have stimulated fears of eventual sentient behavior of machines. These tools also have changed the opportunities available in literature, performance, and art, with powerful tools of investigation and display (e.g., the CGI techniques increasingly dominating the film industry.)

Already we are seeing the spontaneous emergence of new forms of creative activities, e.g., the "maker" fairs providing opportunities to showcase forms of artistic, recreational, and commercial activity; the use of "additive manufacturing" to build new products and processes atomic layer by atomic layer; and the growing use of the "app" culture to empower an immense marketplace of small software development companies. In fact, some suggest that our civilization may experience a renaissance-like awakening of creative activities in the 21st century similar to that occurring in 16th century Europe.

Of course, the creative process of design has long been the culmination of the engineering process, the ultimate application of science and technology to meet the needs of society. As such, engineering design is an intellectual endeavor very similar to that encountered in the creative arts, but distinguished by its rigor and use of scientific and technological tools. Unlike research, which attempts to induce general conclusions from specific experiences, engineering design is rigorous deductive process that develops a specific solution to meet a specific need from a general set of principles. Engineering design is a far more general, powerful, and disciplined approach than mere invention. In addition to innovation, ingenuity, and creativity, design requires great skill and training. It is not an activity left to happenstance, to accidental discovery. Rather engineering design is approached with the disciplined methodology of engineering problem solving.

Ironically the immense importance of design in addressing the myriad needs of a rapidly changing world has not received the visibility and priority of other activities such "creativity", "innovation, and "entrepreneurship" that are clearly dependent upon it. So, what to do to provide this rigorous intellectual skill, so critical to innovation, entrepreneurship, and economic growth, with the priority and support that it requires?

Universities will play a key role, since the creativity required for design must be a goal of engineering education. Indeed, A determining characteristic of the university of the 21st Century may be a shift in intellectual focus, from the preservation or transmission of knowledge, to the process of creation itself.

But here lies a great challenge. As noted earlier, creativity and innovation are key not only to problem solving but more generally to achieving economic prosperity, social well-being, and national security in a global, knowledge-driven economy. Yet, while universities are experienced in teaching the skills of analysis, we have far less understanding of the intellectual activities associated with creativity. In fact, the current disciplinary culture of our campuses sometimes discriminates against those who are truly creative, those who do not fit well into our stereotypes of students and faculty.

The university may need to reorganize itself quite differently, stressing forms of pedagogy and extracurricular experiences to nurture and teach the art and skill of creation and innovation. This would probably imply a shift away from highly specialized disciplines and degree programs to programs placing more emphasis on integrating knowledge. There is clearly a need to better integrate the educational mission of the university with the research and service activities of the faculty by ripping instruction out of the classroom–or at least the lecture hall–and placing it instead in the discovery and tinkering environment of studios or workshops or "hacker havens".

Here, the University of Michigan provides an interesting example of how academic programs characterized by technology-driven creative activities might evolve. On the University's North Campus, we already are fortunate to have several schools–music, dance, and the performing arts; art and design; architecture; and engineering–that focus on the creative activities that increasingly require new tools. The Media Union (aka Duderstadt Center) and adjacent Arthur Miller Theatre on the North Campus provide unique "commons" facilities, gathering places that support interdisciplinary activities in "making things"–3-D objects, virtual reality simulations, new art forms, CGI-based performances, responding to a growing need for both student learning and faculty participation in such activities. In fact, recapturing the original vision of the Media Union as an innovation commons or creation space where students, faculty, and staff from multiple disciplines gather to create, invent, design, and even make things (whether objects of art, performances, buildings, or new technologies). In fact, the four deans of these schools who created the concepts for the Media Union and Walgreen Center in the 1990s used to refer to the North Campus as the University's "Renaissance Campus.

Drawing together aspects of hardware and software, inquiry and discovery, tinkering and invention, and creativity and innovation, experimentation and performance, the Duderstadt Center and Walgreen Center provide tremendous interactive playground for imaginative scholars and students. The tools in these facilities are so easy to use that ideally they become natural extensions to everyday activity. For example, an artist, an engineer, and a choreographer should be able to think up a new staging for a performance together, sketch it out in three dimensions on a computer, then show it off and discuss it in real time with colleagues both here and across the world, all without noticing the complex technology that allows them to collaborate.

Particularly key in this effort is the earlier goal of diversity. As Tom Friedman noted in a New York Times column, "The sheer creative energy that comes when you mix all our diverse people and cultures together. We live in an age when the most valuable asset any economy can have is the ability to be creative–to spark and imagine new ideas, be they Broadway tunes, great books, iPads, or new cancer drugs. And where does creativity come from? To be creative requires divergent thinking (generating many unique ideas) and then convergent thinking (combining those ideas into the best result)." And where does divergent thinking come from? It comes from being exposed to divergent ideas and cultures and people and intellectual disciplines. (Friedman, 2011) Just what a world-class research university characterized by great socioeconomic diversity can offer!

Concluding Remarks

America's leadership in engineering will require both commitment to change and investment of time, energy, and resources by the private sector, federal and state governments, and colleges and universities. Bold, transformative initiatives are necessary to reshape engineering research, education, and practice to respond to challenges in global markets, national security, energy sustainability, and public health. Sometimes a crisis is necessary to dislodge an organization from the complacency that arises from past success. The same holds for a nation–and a profession, in fact. It could be that the emergence of a hypercompetitive, global, knowledge-driven economy is just what the United States and the profession of engineering need.

The growing tendency of American industry to outsource engineering services and offshore engineering jobs should serve as a wakeup call in our times similar to that provided to industry by the outsourcing of manufacturing the 1980s. The global knowledge economy is merciless in demanding that companies seek quality services at minimal cost. When engineers in Bangalore, Shanghai, and Budapest produce high-quality results at one-fifth the cost of similar efforts in the U.S., America's engineering profession simply must recognize that our engineering core competency is no longer particular technical skills or narrowly tailored engineering careers. It requires new paradigms for engineering practice, research, and education. The magnitude of the challenges and opportunities facing our nation, the changing demands of achieving prosperity and security in an ever more competitive, global, knowledge-driven world, and the consequences of failing to sustain our engineering leadership demand bold new initiatives.

Yet we also acknowledge that the resistance to the bold actions proposed in this paper will be considerable. Many companies will continue to seek low-cost engineering talent, utilized as commodities similar to assembly-line workers, with narrow roles, capable of being laid off and replaced by offshored engineering services at the slight threat of financial pressure. Many educators will defend the status quo, as they tend to do in most academic fields. And unlike the professional guilds that captured control of the marketplace through licensing and regulations on practice in other fields such as medicine and law, the great diversity of engineering disciplines and roles continues to generate a cacophony of conflicting objectives that inhibits change.

Yet the stakes are very high. During the latter half of the 20th century, the economic leadership of the United States was largely due to its capacity to apply new knowledge to the development of new technologies. With just 5% of the world's population, the U.S. employed almost one-third of the world's scientists and engineers, accounted for 40% of its R&D spending, and published 35% of its scientific articles. Today storm clouds are gathering as inadequate investment in the necessary elements of innovation–education, research, infrastructure, and supportive public policies–threatens this nation's technological leadership. The inadequacy of current government and industry investment in the long-term engineering research necessary to provide the knowledge base for innovation has been revealed in numerous recent reports. Furthermore, the growing compensation gap between engineering and other knowledge-intensive professions such as medicine, law, and business administration coupled with the risks of downsizing, outsourcing, and offshoring of domestic engineering jobs has eroded the attractiveness of engineering careers and precipitated a declining interest on the part of the best U.S. students. Current immigration policies combined with global skepticism about U.S. foreign policy continue to threaten our capacity to attract outstanding students, scientists, and engineers from abroad.

If one extrapolates these trends, it becomes clear that our nation faces the very real prospect of losing its engineering competence in an era in which technological innovation is key to economic competitiveness, national security, and social well-being. Bold and concerted action is necessary to sustain and enhance the profession of engineering in America–its practice, research, and education. While it is important to acknowledge the progress that has been made in better aligning engineering to the imperatives of a rapidly changing world and to commend those from the profession, industry, and higher education who have pushed hard for change, it is also important to recognize that we still have many more miles to travel toward the goal of better positioning American engineering to serve a rapidly changing world.

References

AAAS (American Association for the Advancement of Science). 2007. *Analysis of R&D in the FY 2008 Budget*. Available online at: http://aaas.org/spp/rd/pre/08pr.htm#hs.

Augustine, Norman (chair), *National Academies Committee on Prospering in the Global Economy of the 21st Century. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, D.C.: National Academies Press, 2005.

Bucciarelli, Louis and David Drew, "Liberal Studies in Engineering–A Design Plan", *Liberal Studies in Engineering*, Special edition of J. International Network for Engineering Studies, Vol 7, Numbers 2-3, 2015*Liberal Studies in Engineering*, Special edition of J. International Network for Engineering Studies, Vol 7, Numbers 2-3, 2015

Clough, G. Wayne (chair). *The Engineer of 2020: Visions of Engineering in the New Century*, National Academy of Engineering, Washington, DC: National Press, 2004.

Clough, G. Wayne (chair). *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academy of Engineering, Washington, DC: National Press, 2005.

Clough, G. Wayne. "Reforming Engineering Education", *The Bridge*, Washington, DC: National Academy of Engineering, 2006.

Continental AG. "In Search of Global Engineering Excellence: Educating the Next Generation of Engineers for the Global Workplace". Hanover, Germany, Continental AG, 2006. (Available at http://www.conti-online.com)

Council on Competitiveness, *Innovate America: Thriving in a World of Challenge and Change*. The National Innovation Initiative. Washington, DC: Council on Competitiveness, 2005. http://www.compete.org/nii/

Duderstadt, James J. (chair). *National Academy of Engineering Committee to Assess the Capacity of the United States Engineering Research Enterprise, Engineering Research and America's Future: Meeting the Challenge of a Global Economy*. Washington, D.C.: National Academies Press, 2005. www.nap.edu.

Friedman, Thomas. *The World Is Flat: A Brief History of the 21st Century*. New York: Farrar, Strauss, and Giroux, 2005.

Grasso, Domenico and David Martinelli. "Holistic Engineering", *Chronicle of Higher Education*, Marcy 16, 2007, pp. B8-B9.

Kam, Moshe and Arnold Peskin. "What Should Be the First Professional Degree in

Engineering", *The Institute*. Washington: IEEE, 2006.

Lohman, Jack R. (editor), Special Issue: The Art and Science of Engineering Education Research, *Journal of Engineering Education*, January 2005.

National Academy of Engineering. The Offshoring of Engineering: Facts, Myths, Unknowns, and Implications, October 25, 2006. See website: http://www.nae.edu/nae/engecocom.nsf/weblinks/PGIS-6SKKK2?OpenDocument

OSTP (Office of Science and Technology Policy). *The American Competitiveness Initiative*. Washington, DC: U.S. Office of Science and Technology Policy, 2006 (http://www.ostp.gov/html/ACIBooklet.pdf).

Pister, Karl S. and C. Judson King, "How Best to Broaden Engineering Education", *Liberal Studies in Engineering*, Special edition of J. International Network for Engineering Studies, Vol 7, Numbers 2-3, 2015

Schowalter, W. R., "The Equations (of Change) Don't Change, But the Profession of Engineering Does", *Chemical Engineering Education*, American Society for Engineering Education, 2003.

Sheppard, Sheri D., "Taking Stock: A Look at Engineering Education at the End of the 20th Century and Beyond", *American Society for Engineering Education*, June 19, 2006.

Vest, Charles M. "Educating Engineers for 2020 and Beyond", *The Bridge*, Washington, DC: National Academy of Engineering, 2006. 38-44.

Wulf, William. A. Annual Address. Annual Meeting of the National Academy of Engineering, October 12, 2003.