2007 Hoyt Memorial Lecture

THE ENGINEERING PROFESSION IN THE 21ST CENTURY – EDUCATIONAL NEEDS AND SOCIETAL CHALLENGES FACING THE PROFESSION

Diran Apelian
Director, Metal Processing Institute
Worcester Polytechnic Institute
Worcester, MA USA

Abstract

As author and journalist Thomas Friedman has declared, the world is now flat and globalization of the economy has amplified the impact of technology on modern societies in ways that could not have been predicted. The connectivity provided by the Internet has generated new markets for products and services, but also has made available labor that is often both educated and cheap. This is having a profound impact on the distribution of wealth in both the developed and the developing part of the world.

That education plays a role in the prosperity of nations is not debated, but many authors argue that it is specifically the presence of both knowledge and know-how that determines how well off societies are. The education of engineers is therefore critical to every nation to ensure the prosperity of their citizens. The engineering profession in the 21st Century is evolving between developing and developed countries in light of certain aspects of engineering talent becoming a commodity.

The 2007 Hoyt Memorial Lecture addressed the re-engineering of engineering education for the 21st century to address these changing paradigms; the focus was on the materials engineering profession and the metals processing industry.

Introduction

Engineering education and the profession are confronting a challenging crossroad. Some of us see it as a crisis, others, as an opportunity for positioning our community and our society for the 21st Century. It would be fair to say, however, that none of us are very satisfied with the status quo and what seems to be facing us in the near term. As Charles Dickens cited in the opening phrase of *A Tale of Two Cities, "It was the best of times, it was the worst of times."*

As author and journalist Thomas Friedman has declared, the world is now flat [1] and globalization of the economy has amplified the impact of technology on modern societies in ways that could not have been predicted. The connectivity provided by the Internet has generated new markets for products and services, but has also made available labor that is often both educated and cheap. This is likely to have a profound impact on the distribution of wealth in both the developed and the developing part of the world and may, in particular, alter the socio-economic structure of countries where the general well-being of the population has been taken for granted. That education plays a role in the prosperity of nations is not debated, but many authors, like Landes [2] for example, argue that it is specifically the presence of both knowledge and know-how that determines how well off societies are. The education of engineers is therefore critical to every nation to ensure the prosperity of their citizens. The basis of what follows is based on these premises:

- Knowledge and know-how determine how well off societies are compared to other societies.
- Education of engineers is critical to every nation to ensure the prosperity of their citizens.
- Standard of living hinges on our ability to educate a large number of sufficiently innovative engineers.
- R&D spending fuels innovation.
- Creation of wealth is related to a nation's ability to make products that other nations want to purchase.

The modern professional identity of engineers emerged in the early eighteenth century with the establishment of the Ecole Polytechnique in France and the foundation of professional engineering societies in England. The current way of educating engineers, including the structure of the curriculum, was already established by the early twentieth century, but the course content has, of course, changed significantly since then. The last major shift in engineering education in the United States goes back over half a century when the role of science in the educational program increased significantly [3]. Although some evolution certainly has taken place, those changes are relatively modest and the basic structure and course content of a modern engineering program is very familiar to someone educated in the sixties. Moreover, the engineering curricula developed in the West is the curricula that is being taught in the developing countries perhaps with more intensity, and to an audience (students) that are quite eager to learn. Much of the engineering talent is becoming a commodity.

The question as to how we in the developed countries and specifically in the U.S. differentiate ourselves is a pivotal one as we enter the 21st Century.

The time for another major re-examination of engineering education is overdue. Countless committees, taskforces, panels, and commissions have already addressed the need and eloquently emphasized that the competitiveness of the country and therefore the general standard of living hinges on our ability to educate a large number of sufficiently innovative engineers [See, for example 4, 5, 6, 7, 8]. Figure 1 clearly shows the concern with respect to manufacturing production, especially when one compares the production in the U.S. to Japan and China [9]. This is even more concerning when one considers that creation of wealth is related to a nation's ability to make products that other nations want to purchase.

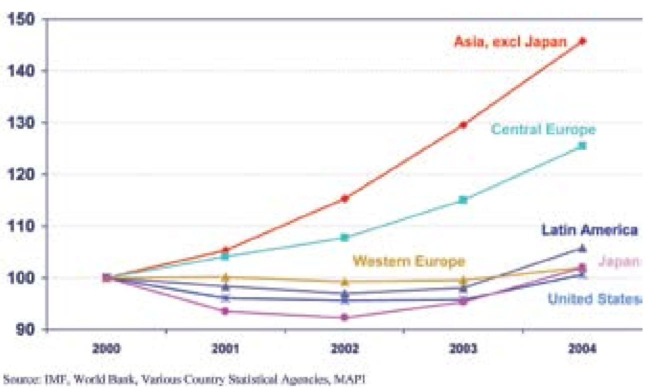

Figure 1. Manufacturing production by region of the world [9].

That the world has changed in fundamental ways during the last decade or two is self-evident. Computers have fundamentally altered the way we live and work. They have, in particular, transformed our ability to deal with information and data. We are now moving rapidly toward a world where—for all practical purposes—we can *process information infinitely fast, store infinite amount of data, and transmit data instantaneously*, to paraphrase a statement made by Henry B. Schacht, the first chairman and CEO of Lucent Technologies Inc. in his commencement speech at Worcester Polytechnic Institute (WPI) in 2001. As a result of the emergence of the Internet, knowledge has been "communalized." Everybody has access to information about anything and—perhaps equally importantly—knowledge is no longer "owned" by the experts. Computers have also empowered the average man and woman to create products that previously required large corporations with significant resources. In many aspects of digital media we have now reached the point that if we can imagine it, we can create it. As computer speed and software advances, this trend will continue and in twenty years or so it is very likely—almost certain, actually—that a high-school student with a laptop, and a little bit of time, will have the capability to create his or her full length animated movie with virtual actors of the quality currently only produced by major movie makers. The same transformation is likely to happen to the creation of engineered artifacts, although the time frame may be somewhat longer. Ordering components through the web and receiving them in the mail is now part of everyday life and e-manufacturing—where the customer sends an electronic description of a part to a manufacture who makes it and mails it back—is emerging.

The globalization of the world economy affects everyone. The motion of labor intensive but low-skill industries to countries with low labor costs is, of course, not new. Such transfer has been largely responsible for the low cost and abundance of most manufactured goods and the rising importance of service over "stuff." Today, however, the rise in education in nations where salaries are low and the connectivity that makes this cheap and educated talent available worldwide are gradually changing the nature of jobs that move oversees. Skill is rapidly becoming a commodity that can be bought from low-cost providers anywhere. It does not matter what you know how to do, someone else knows it too and is willing to do it for less.

The mechanization of labor and advances in transportation, taking place during the last century, coupled with the more recent information revolution and globalization of the economy, has brought unprecedented opportunities and challenges. On the positive side is that the increase in our material wealth makes it—for the first time in history—realistic to talk about eliminating extreme poverty [10]. On the negative side is the possibility—for the first time in history—that human consumption of materials and energy may irreversibly damage the entire global environment [11]. Engineering in the new world is therefore both a daunting and an exciting undertaking!

Societal Context

Between 1946 and 1972, during the so-called golden age of the American economy, the medium family income doubled from about $16,000 to $32,000. However, since the early 70s, the medium family income has not dramatically increased, but what is more startling is the difference between high school graduates and college graduates. This difference has tripled.

While the economic pie is not growing rapidly, those with post secondary education are getting bigger shares and those with graduate degrees are getting even bigger shares. The historical perspective will help us to understand what has caused these sea changes.

From the Civil War to the 1970s, the U.S. was the world's most successful mass production economy. The U.S. was the very best at producing standardized goods and services at the least cost and selling them at the lowest price. We as an American society organized a mass production work force and an industrial system without peer in the modern world. We built machinery to mass produce standardized components and we used unskilled labor to tend the machines and install broadly assigned white collar and technical elites at the top of the organizational structure. The elites orchestrated the piece meal work of the narrowly skilled and narrowly assigned workers, and the parts of products and services they produced into final output. In the early days, authoritarian management systems allowed us to increase the scale of operations and output at rapidly declining cost.

In tandem, we built a mass education system to support our mass production economy. We provided a broad and liberal education for those at the top of the house, and really not much education at all for those at the bottom of the hierarchy. This seemed to work. We became a consumer-oriented society where work was not important; rather, the output was.

When the mass production system failed in the Great Depression, we learned how to protect mass production against economic calamities. The economist Keynes entered the pictured. He advocated that by stimulating consumption we create work. Under-utilized resources were put to work through increased government spending, tax reduction or by even printing money. The Keynesian solution to instability in a mass production economy was an economic and political miracle. In a retrospective way, it allowed us to run the economy without putting our hands on it and by simply manipulating economic aggregates. But all that changed in the early 70s. Suddenly we found that our mass production system seemed to lose its competitive edge. Our allies and our enemies in the Second World War had recovered and were competing, and competing fiercely, with us again. Initially, they tried to emulate the spectacular success of American mass production, but very quickly they learned that if they mass-produced they would fail. They simply did not have a big enough domestic market. So, it was through necessity, that they learned to sell to a variety of foreign markets and, to do so, they had to build work systems that were more flexible in order to produce variety. They also learned to emphasize quality in order to compete with mass production. It is for these historical reasons that we see more authority in the skilled workers down the line in both Europe and the Pacific Rim in order to build quality inter-productive systems.

In order to improve products and services continuously, institutions have to be capable of learning and embracing a culture of learning. This is where the knowledge era enters. Learning organizations are those where information not only flows from the top down, but where information and knowledge flow freely throughout the institution. In the learning organization, every worker and every work site has to be a listening post for new ideas and product improvements. The mass production organizations of large corporations, big government, and higher education do not have that kind of sensitivity. The dilemma is that by merely installing flexible technology and flexible work systems and giving workers the autonomy to exploit the new flexibility has proved to be insufficient. Empowering people without enabling them with skills necessary to exercise their new autonomy is really a hollow exercise.

In a global economy driven by relentless innovation, what a company knows has become as important as what it produces. The knowledge era is very much the underlying force as we enter the 21st Century. Success in the marketplace is increasingly linked to an organization's ability to manage and leverage its intellectual capital - the intangible and often invisible assets such as knowledge and competence of people, intellectual property and information systems that do not show up directly on the bottom line but, I believe, are just as valuable as financial assets. Education models and paradigms for the engineering profession for the 21st Century need to address these critical issues.

Almost a decade ago, The Federal Trade Commission held hearings on the topic of "Anticipating the 21st Century". We at the Metal Processing Institute, through the Sloan Foundation, participated in these hearings that lasted over seven weeks and resulted in a report containing a detailed analysis and specific recommendations. Two premises were confirmed [12]:

> *"First, global competition-that is imports, exports, cross border investments, and international joint ventures-is expanding at a rapid rate. U.S. firms can no longer be content with besting domestic competitors; their fiercest rivals now are often foreign firms. Second, in many markets, the basis for competition today includes not only the price at which a product is sold but the ingenuity, variety, and speed of development of new goods and services."*

Driving the dramatic change in today's economy are technology, global competition and deregulation - and they are likely to accelerate in the years ahead. These forces cannot be ignored nor legislated out of existence. The changes require a new way of working, a new paradigm of the workplace, and investing in the most important capital we have–human assets. Engineering education as we enter the 21st Century needs to address these challenges.

Historical Context

History shows that we in the U.S. took our roots and our values from many different lands, and, in particular, we became the heirs to both the French and British cultures.

Louis XV established a civilian engineering corps to oversee the design and construction of bridges and roads in France. In 1716 he established an organization called the Corps des Ponts et Chaussées, which subsequently established a school to train its members; in 1747 Ecole des Ponts et Chaussées was founded in Paris - the very first engineering school ever. This led to the founding of other technical schools in France, the Grandes Ecoles. The famous Ecole Polytechnique of Paris was founded in 1794 by Napoleon. The French recognized engineering as a noble profession that prepared the future statesmen and leaders of their society. In fact, the word *ingenieur* stems from the word genie meaning genius, which is quite different from some of the connotations with respect to engineering and engines. The famous mathematician Laplace wrote that the Ecole Polytechnique's goal is to produce young people "Destined to form the elite of the nation and to occupy high posts in the State." The graduates of these Grandes Ecoles have over the years proven their "power" by occupying posts in the highest economic strata of French society [13]. In France the "polytechnicien" reigns supreme.

On the other hand, as one reviews the evolution of engineering in Britain, we see a very different path. The English upper class believed in a much more classical education wherein the bright young males sought careers in the church or in the army. There was no meaningful governmental funding of higher technical education during the industrial revolution and it was not till the early 1900s that Cambridge and Oxford Universities established chairs in Engineering Science. Much of the industrial revolution was driven by individual ingenuity and entrepreneurial initiative. Knowledge was gained pragmatically in workshops and on construction sites. Apprenticeships became the way young men went into engineering. As Samuel Florman has characterized it – "In France engineering became associated with professional pride and public esteem, with leadership at the highest level. Whereas, in Britain, engineering was considered a navvy occupation–the original navvies being the laborers on canal construction jobs" [13, 14]. Both of these cultures, the theoretical foundation emphasized by the French Ecoles and the practical hands-on attitude of the British, permeated across the Atlantic and impacted the development of engineering education in America. Although it is possible to argue that the marriage of theory and practice played no small part in the phenomenal successes of American engineering in the 20th Century, finding the right mix occupied engineering educators throughout the century.

As engineering education has changed in the past to adjust to the needs of society, the evolution must continue and change is needed to address the needs of the 21st Century. With many approximations and generous error bars, we can summarize major trends in engineering education by the following classification (for a more fine-grained classification see [15]):

19th century and first half of the 20th century: professional engineer—As engineering became a distinct profession, early engineering programs focused on providing their graduates with considerable hands on training. However, the role of science and mathematical modeling slowly increased and gained acceptance.

Second half of the 20th century: scientific engineer—By mid century, technological progress, including the successful harnessing of nuclear energy, as well as geopolitical realities as materialized by Sputnik, drove home the need for engineers to be well versed in science and mathematics and the engineering curriculum adjusted to the changed needs. This structure has, to a large degree, continued until the present time, although "design" content increased slowly. In the early nineties it was clear that more than science was needed and many schools started to emphasize non-technical professional skills such as teamwork and communications

The 21st century: entrepreneurial/enterprising engineer—The rapid changes that the world is currently going through, as discussed above, coupled with changes in engineering education starting to take place in the nineties, are likely to result in an extensive re-engineering of engineering education. While the new structure will, almost certainly, continue to be based on a solid preparation in mathematics and sciences, it is likely to emphasize the professional role of the engineer, and then demand new qualifications suited for the new world order.

The Engineering Profession and the Engineer Of The 21st Century

We cannot, of course, say what the engineering profession will look like hundred years from now. The intense discussions that are currently taking place [4, 5, 6, 7, 8] among leaders of the profession and educators suggest that innovation will be a central theme. The premise is that skill is a commodity and that routine engineering services will be available from low cost providers that can and will be located anywhere in the world. The engineering education therefore has to add value beyond just teaching skills. That skill is or will become a commodity does, of course, not mean that future engineers do not have to possess skills. Quite the contrary, they will have to be even more technically proficient than those making a living today practicing narrowly defined tasks. The engineers of the twenty-first century must constantly be able to gather information and decide on a course of action, including what tools are needed for a given task. The technical skills, the people skills, and the innovation required of the future engineers can be summarized—with only modest exaggerations—as follows:

The entrepreneurial engineer of the twenty-first century

- **Knows everything**—can find information about anything quickly and knows how to evaluate and use the information. The entrepreneurial engineer has the ability to transform information into knowledge.

- **Can do anything**—understands the engineering basics to the degree that he or she can quickly assess what needs to be done, can acquire the tools needed, and can use these tools proficiently.

- **Works with anybody anywhere**—has the communication skills, team skills, and understanding of global and current issues necessary to work effectively with other people.

- **Imagines and can make the imagination a reality**—has the entrepreneurial spirit, the imagination, and the managerial skills to identify needs, come up with new solutions, and see them through.

How do we educate someone barely into their adult life to possess these qualifications? Or, for that matter, do such generalized statements mean anything concrete? Our contention is that they do and that first of all, these goals translate into specific curricular requirements and second, that we are well on our way to achieve some of these goals—or that we at least see how to proceed.

The first goal—knowing anything—is relatively easy. We can now "google" any concept and the probability is that we will have an abundance of information in a matter of seconds. And as search engines become more sophisticated the probability that the information is relevant will increase. The transformative effect of being able to access information instantaneously cannot be overemphasized. We all "know more than we know" because in addition to knowledge we possess we also know where to find information about specific things. Most of us know how to fix our computers, not by knowing so ourselves, but by knowing whom to ask. The introduction of the internet expanded this network of contacts to literally every piece of information that is out there. However, while finding information is already trivial, the communalization of knowledge will make it essential for the professional engineer to be able to judge the quality of the information that he or she has. Thus, teaching to how to deal with an abundance of information and how to judge the relevance and the quality of the information at hand will be the educational challenge.

Engineers have always learned as they tackle new challenges. The explosion in the availability of tools to do nearly everything does, however, suggest that engineering educators must rethink how students are prepared in the foundation of their disciplines. Computer programs to do virtually anything, from conducting simple calculations to simulate complex systems to design a complete engineered artifact, empower the modern engineer to do more than his or her predecessors could ever imagine. These tools do, however, not only require that the engineer knows how to use them, but also require him or her to be able to first of all to assess what tool is appropriate for a given task and then to be able to evaluate the result in a critical way. "To err is human, but to really screw up you need a computer," so the importance of common sense will be even greater when design and analysis are done exclusively on the computer. While teaching engineering students how the physical world works is at the core of engineering education today, re-examining how we teach the fundamentals of engineering science to students is needed. Knowing the scale of phenomena and the distribution of knowledge over multi-scales are critical attributes.

In addition to the changes in the technical skills engineers must possess, their non-technical professional skills must be suited for the modern way of doing engineering. Considerable progress has already been achieved in the United States to make communication in the broadest sense an integral part of the engineering curriculum [9,10]. Most programs now require their graduates to exhibit proficiency in oral and written communications and to be able to work on diverse teams. Engineering, possibly more than most professions, requires accurate and efficient communications—I have to understand what you are saying and vice versa for the design that we both are working on to function. The surprising thing about communications is not that engineering schools have recently started to emphasize it (motivated by ABET [16], in some cases), but that there ever was a need to remind educators that engineers need to communicate! However, in a flat world the ability to communicate takes on a much broader meaning. Not only are engineers frequently working on products that will be made in a different country and marketed to people of different cultures, but product engineering is increasingly done by teams consisting of people located in different countries and with diverse cultural background. Such interactions obviously have enormous potentials for misunderstanding and conflicts. To make the case, we quote Ron Zarella CEO of Bausch and Lomb who said, in a speech that he gave at WPI during a globalization workshop:

> *"We make a product called interplak. The electromechanical design for this home plaque-removal device is done in Germany and Japan. The batteries are supplied from Japan, the motors are built in the Peoples Republic of China, the charging base is made in Hong Kong, the precision molded plastic pieces are manufactured in Atlanta, GA, the brush head is made in Ohio, and the final assembly is done in Mexico."*

Preparing young engineers to work in a flat world is no longer something that engineering schools can treat as an extracurricular activity, available only to those that have the time and resources to spend an extra semester abroad. Every student must now develop the attitudes and skills necessary to function globally, right from the time they first enter the workforce.

With skill becoming a commodity, the engineer of the future must be able to do more than just perform technical tasks. There have always been extraordinary engineers who have had the imagination, vision, dedication, and endurance to change the way we live. Those who have not have, however, in the past been able to make a living performing routine engineering tasks. The young engineers of the future must, on the other hand, all be extraordinary. They will not be able to enjoy the comfort of well-paid jobs where routine tasks are performed more or less unchanged year after year. More and more the engineer of the future will be responsible for creating new ideas and solutions and seeing them through. Innovation has already been identified as one of the most important factors in the future prosperity of both nations and individuals [1, 2, 7, 8]. The engineering challenges are, however, even greater. Not only must the engineer innovate, he or she must be able to help the innovation become a reality. Thus, the education of the engineers of the future must prepare them to see new opportunities as well as to give them the skills needed to marshal the resources to realize their ideas.

Source of Human Asset—*Pipeline Issues*

Engineering curricula have become a commodity and are now available to students all over the world via the net. What will differentiate the US engineering graduate from those in other countries? To remain competitive, we must graduate innovative leaders for an increasingly technological society. Innovation, creativity and entrepreneurship as well as the societal context of engineering ought to be central to the new curriculum for the 21st Century. Linkages between the engineering profession and societal needs ought to be explicitly articulated; the latter will inspire and attract students to the profession.

The dilemma we are facing in the US is that the interest in engineering is declining and more significantly it is declining with white males [17]–see Figure 2. Furthermore, if we examine the "production" of engineering graduates around the globe, we in the US lag many of the G7 countries – see Figure 3. What is most alarming is the performance of our students in the basic sciences in comparison to many other countries – see Figure 4. It is clear that much work needs to be done to revitalize the interest in engineering, and to articulate that engineering is a social enterprise.

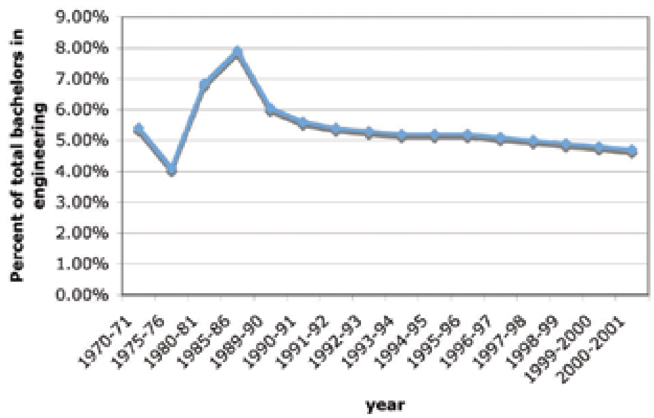

Figure 2: Percent of total bachelor's degrees granted that are in engineering [17].

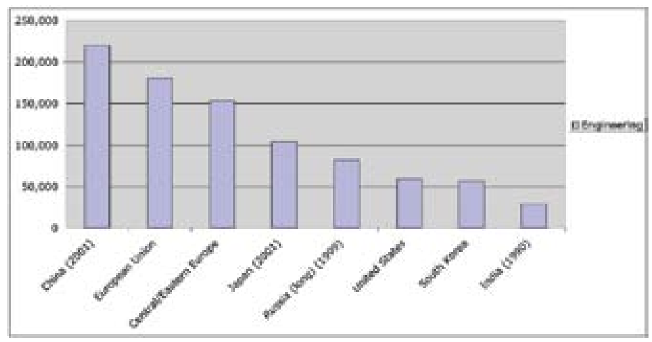

Figure 3: Engineering degrees granted by country, 2002 [18].

Country	Mean Score	Country	Mean Score
Finland	548	Poland	498
Japan	548	Slovak Republic	495
Hong Kong (China)	539	Iceland	495
Korea	538	**United States**	**491**
Liechtenstein	525	Austria	491
Australia	525	Russian Federation	489
Macao (China)	525	Latvia	489
Netherlands	524	Spain	487
Czech Republic	523	Italy	486
New Zealand	521	Norway	484
Canada	519	Luxembourg	483
Switzerland	513	Greece	481
France	511	Denmark	475
Belgium	509	Portugal	468
Sweden	506	Turkey	434
Ireland	505	Mexico	405
Hungary	503	Brazil	390
Germany	502		

SOURCE: OECD, available at www.pisa.oecd.org.

Figure 4: Mean Scores in science (2003 data) for various regions of the world as documented by the Program for International Student Assessment (PISA) [19].

One avenue to attract students and to address many of the needs described above is through internship programs such as the ones we have instituted at the Metal Processing Institute (MPI) at WPI. The underlying philosophy of the MPI Internship Program is to provide an educational experience, which is meaningful to the student, is contextual, and one that instills excellence. The Internship Program bridges the gap between classroom learning and industrial experience. Unlike co-op programs, the internship program ensures that the industrial internship project is tied in with the academic plan of the student. The MPI Internship provides a holistic and contextual educational experience - a new paradigm in graduate education. The internship concept is applicable to both undergraduates and graduate students [20].

Proactive Recommendations

Engineers solve problems, make things happen and enhance the quality of life on this planet. This has always been a constant; however what changed over time have been the needs of our society and how engineers have responded to those needs. During the late 1800's, Engineers are credited with profound innovations and inventions to meet the needs of the Industrial Revolution. Engineers made things, built bridges, and established mass production; in so doing they transformed us from an agrarian society to an industrial one. In the 1900's with the advances in solid-state physics and our understanding of the atomic structure, engineers learned science and became scientists because they needed the science base to solve the problems facing society. This includes the needs for defense (A bomb, supersonic aircrafts, weaponry) to the development of the semiconductor, and the electronic materials revolution (Information age), among many other inventions. As we enter the 21st Century, globalization and "flattening of the World" is a reality that is transforming the role of engineers and engineering. For the 21st Century, engineers need to be enterprising and must lead to address the needs of our society (global society). With 20% of the world population living in absolute poverty, 18% of the population lacking access to safe drinking water, 40% having no access to sanitation, energy consumption increasing at a higher rate than population growth, and healthcare needs and expectations increasing out of sync with the cost of health care delivery, there is no doubt that the engineer for the 21st Century has to be a social scientist as well as an enterprising leader to meet these needs.

Going forward there are specific actions that we as a community should consider; the underlying theme is that we need to change the image of engineering and we need to fuel the "innovation engine".

Change of Image

At present the public's image of engineers and engineering does not reflect reality. It is a fact that many of our top industrialists and successful CEOs are engineers; we have many surgeons and physicians whose first degree is in engineering. We have bankers and financial tycoons who are educated as engineers. There is no limit. The image of engineering needs to be changed to reflect the boundless opportunities and lifestyles that await our graduates.

Back in the early 1900's, engineering educators did not pay attention to the management issues and essentially allowed management to leave the engineering curriculum; we have seen the rise of the MBAs especially after WWII. This was a mistake. Interestingly, the mathematician Laplace who was one of the founding directors of the Ecole Polytechnique in France, said [14]:

> *"The Ecole Polytechnique should aim to produce young people destined to form the elite of the nation and to occupy high posts in the state"*

This was the view of the Polytéchnicien back in 1794. Perhaps we need to revert back to this image and engage our young about the leadership opportunities engineering offers. Moreover, we need to have a unified message. At present, the message regarding engineering as a career path is fragmented. The message articulated by civil engineers (ASCE), mechanical engineers (ASME), metallurgists and materials scientists and engineers (ASM, TMS), electrical engineers, and chemical engineers (AIChE) is not the same. The various messages differ and they ought to be the same – *we need a unified message.*

Societal Issues and Engineering Profession as an Enabling Profession

During the 21st Century we will see our world population increase to about 9.5 billion people (from 6.5 billion) and much of this growth will occur in the developing nations. Societal needs regarding energy resources, transportation, housing needs, packaging materials/recycling, and biomaterials and health will only escalate. The challenges we face for a sustainable development of the globe are immense. This is precisely why engineering should be so attractive to the next generation; we need to make the case that engineering is an enabling profession. The case for engineering as an enabling profession for sustainable development of the globe is powerful; however this connection is not explicitly made.

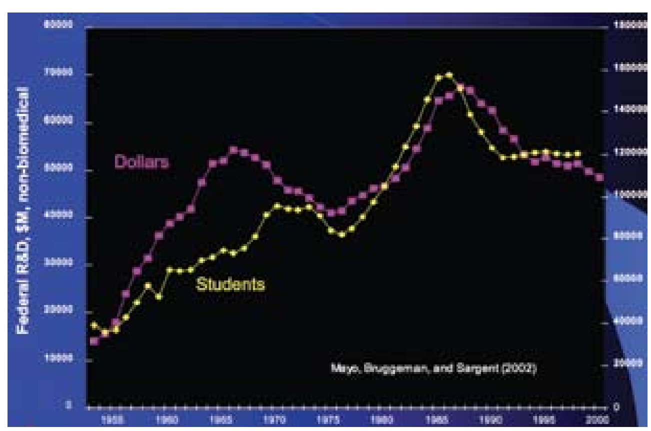

Figure 5: Correlation between Federal R&D funding and the number of students that are in the pipeline. Clearly, R&D funding fuels the "innovation engine" [21].

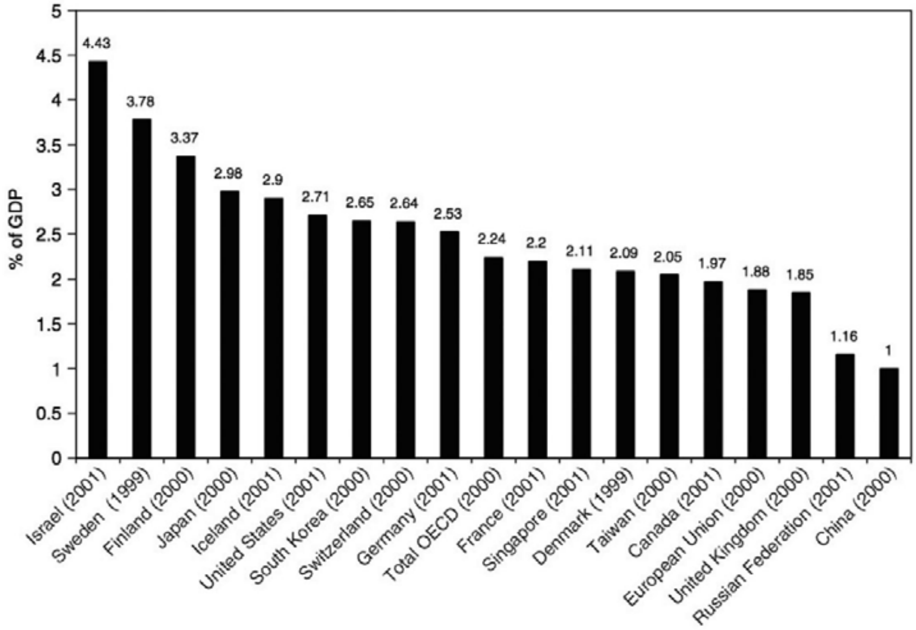

Figure 6: R&D expenditures as a percentage of the GDP [22].

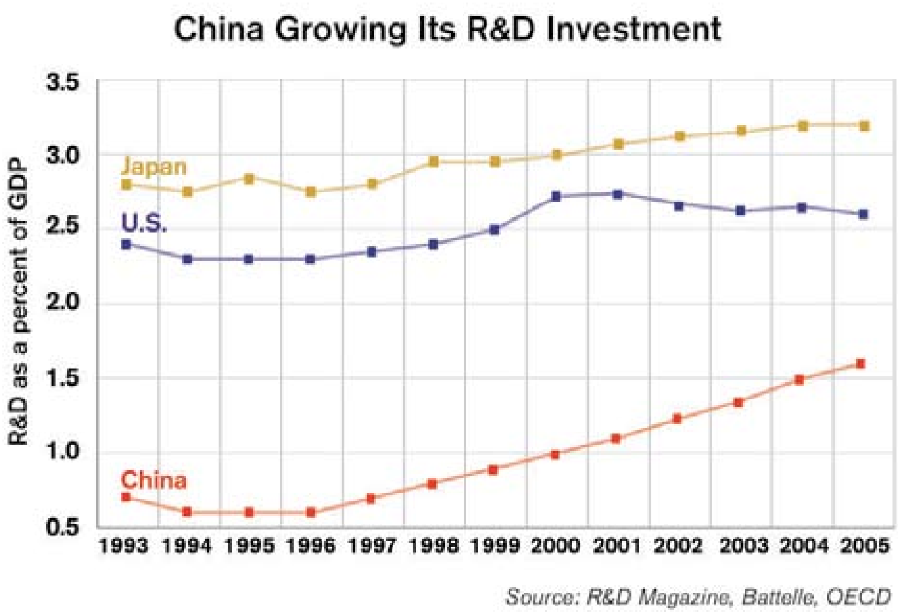

Figure 7: Rate of increase/decrease of R&D expenditures as a percentage of GDP for Japan, USA and China[23].

Fuel the "Innovation Engine"

As can be seen in Figure 5, the correlation between R&D funding and the draw for students pursuing careers in engineering is extremely high. There is no question that R&D attracts students and fuels the innovation engine. Yet, examining the data in Figures 6 and 7 indicates that we in the USA need to reverse the trend. It is important to note that:

- 73% of the citations in U.S. industry patents are from research conducted at publicly supported institutions.
- Economic studies (including those of Nobel Laureate Robert Solow) show "technological progress" accounts for 50% of economic growth, for all time periods studied (various intervals from 1869-1979).
- Strong correlation between federally R&D funding and creation of technically trained workers.

Funding of R&D at the Federal level must escalate to ensure that innovation is abound.

Conclusions

It is unthinkable that our society can remain competitive and that we can sustain the present standard of living without a large number of people with the knowledge and know-how to innovate. In the early days of our nation's birth, Noah Webster claimed that democracy succeeds and prevails only if the people have economic and educational hope, and that these two are closely interlinked. To educate engineers ready to face the challenges of tomorrow we must appreciate how profoundly the world has changed from just a few decades ago. Moreover, we need to embrace these changes and move ahead to ensure that the engineering profession is a social enterprise. We need to educate engineers that are more akin to the French Polytechnicien model: engineers that understand the societal context of their work, have an understanding of the human dimension around the globe, coupled with innovation and creativity. The challenge for us is daunting, both in academia as well as in corporate America. It will be appropriate to conclude by remembering what the Red Queen says to Alice in Through the Looking Glass: *"Now, here, you see, it takes all the running you can do to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"*

References

1 Friedman T.L., *The World Is Flat: A Brief History of the Twenty-first Century*. Farrar, Straus and Giroux, (2005).
2 Landes D.S., *The Wealth and Poverty of Nations, Why Some are so Rich and Some so Poor*. W.W. Norton & Company, (1998).
3 Grinter L. E., *Report of the Committee on Evaluation of Engineering Education, 1955*. Available at http://www.asee.org/resources/beyond/grinter.cfm
4 Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future, National Academy of Sciences (2005). Available at: http://www.nap.edu/catalog/11463.html
5 Tapping America's Potential. The Education for Innovation Initiative. Business Roundtable, (2005). Available at: http://www.businessroundtable.org/pdf/20050803001TAPfinalnb.pdf
6 The Engineering Workforce: Current State, Issues, and Recommendations. Final Report to the Assistant Director of Engineering. National Science Foundation, (2005). Available at: www.nsf.gov/attachments/104206/public/Final_Workforce.doc
7 *The Engineer of 2020: Visions of Engineering in the New Century*. National Academy of Engineering (2004). Available for free online reading at: http://www.nap.edu/catalog/10999.html
8 *Educating the Engineer of 2020:* Adapting Engineering Education to the New Century. National Academy of Engineering (2004). Available for free online reading at: http://fermat.nap.edu/catalog/11338.html
9 "ASTRA briefs" (Vol. 4, No. 6.) June (2005). Available at: http://www.tms.org/PGA/NEWS-policy/ASTRABriefsSummer2006.pdf
10 Sachs J., *The End of Poverty: Economic Possibilities for Our Time*, The Penguin Press, (2005).
11 Brown L., *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble*. Available for free online reading at: http://www.earth-policy.org/Books/PB2/index.htm
12 http://www.ftc.gov/reports/21cent/antic21.htm, accessed February (2007).
13 Apelian D., "Re-engineereing of Engineering Education- paradigms and paradoxes", Alpha Sigma Mu invited lecture, presented at the ASM Fall meeting, Pittsburgh, PA, October 18, 1993; in Advanced Materials & Processes, Vol. 145, No. 6, June (1994), pp. 110-114.
14 Florman S.C., The Existential Pleasures of Engineering, St. Martin's Press (1996).
15 Grayson L.E., *The Making of an Engineer: An Illustrated History of Engineering Education in the United States and Canada*, New York: John Wiley & Sons, Inc. (1993).
16 Criteria for Accrediting Engineering Programs. Accreditation Board for Engineering and Technology, Inc. Available at: http://www.abet.org
17 Noeth, R. J., Cruce, T., and Harmston, M. T., *Maintaining a Strong Engineering Workforce*, ACT Policy Report, (2003).
18 National Science Board, *Science and Engineering Indicators,* National Science Foundation, Arlington, VA, vol. 1, (2004).
19 http://www.pisa.oecd.org, accessed February (2007).
20 http://www.wpi.edu/Academics/Research/MPI/internships.html, accessed July (2007).
21 Mayo, Bruggeman and Sargent, Science and the Congress Project 2002, http://www.nemw.org/ASTRAMfgRandD111502.pdf , accessed July 2007.
22 Globalization of Materials R&D: Time for a National Strategy http://www.nap.edu/catalog/11395.html
23 R&D Magazine, Battelle, OECD