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Abstract

We live in times of seeming chaos and rapid change. Currently unemployment is rising worldwide and global interdependencies are becoming increasingly apparent. Notwithstanding high levels of unemployment there are reported shortages of workers with specific abilities, experience, technological and other skills ranging from, for example, tool and die makers, through machinists to more sophisticated technologies like nuclear power and optoelectronics. Nevertheless the basic structures of our curricula have experienced only fairly minor augmentation during recent decades. By employing a teleological view and examining past trends the attributes of a curriculum suitable for the future workforce are postulated. Historical data on industry revenues and workforce numbers is taken from two sources: (a) Fortune 1000 for large (and global) enterprises and (b) US Department of Commerce/Bureau of Labor Statistics for operations of all sizes in the US. Experience with K-12 national competitions demonstrates convincingly that the best students are certainly capable of tackling future challenges. Unfortunately when they arrive in college most are compelled to adapt to the curricula constraints of discipline-specific accredited engineering programs.

Introduction

In times of great or seismic change there are great opportunities for those with the imagination and initiative to seize the moment and enable transformations. Often these opportunities seem too enormous, too threatening and not in any context that may be within our zones of comfort. It is then that we tend to focus on achievable details, doing what we can to improve that which is readily within reach. This tendency can almost be likened to 'polishing the doorknobs on the Titanic after hitting the iceberg!'[1] We live in times of seeming chaos and rapid change. It is has been said, quoting Rahm Emanuel, likely from prior sources, that we should never let a good crisis go to waste.[2] Opportunities of this nature have also been highlighted by former Intel leader, Andrew Grove, as 'strategic inflexion points.'[3]

In the US, and elsewhere in the developed world, there is appreciable focus on education, many concerns are being expressed. Lesser developed nations and many larger and increasingly prosperous countries appear to be following American and European pedagogic models. These models essentially carve up science, applied sciences and engineering into specific disciplinary parcels that tend to be delivered in tightly prescribed curricula. There are continual endeavors to develop, augment and modify curricula but as a rule these tamper with details around the fringes of the structured and accredited disciplines. Cross-disciplinary options are made available, also minors with program titles designed to attract customers – the students, their parents and industry. Time to graduation also tends to increase as courses are added and very few topics are eliminated. Concurrently in the both Europe and the US there are shortages of engineering and science graduates and concerns for the overall technological literacy of our future populations (although their abilities to master iPODs, iPhones, MP3 players, Wii devices and FaceBook are unmatched).

It may be an oversimplification, but it can credibly be alleged that the basic structure of engineering education has changed very little in the last half-century notwithstanding absolutely enormous changes in the organizations and products produced by the global and local industries hiring new graduates. Yes, our best graduates are capable of adapting to the world of industry that they enter, but is it possible to imagine and create more efficient effective pedagogic procedures and curricula? Most particularly could new totally rethought curricula attract more students into gaining credentials to equip them for the engineering tasks facing future generations?

The Changing Workplace

Previous studies,[4] augmented by Foote and Pender[5], show that industry output and revenues have been increasing both for the larger Fortune 1000 companies (with US HQ addresses) and for the smaller US businesses reported by the Department of Commerce and the Bureau of Labor Statistics. In general this increased productivity has been accompanied by appreciable restructuring and workforce decline. The overall 'goods producing' workforce declined by 9.9% between 1999 to the end of 2008 and 'manufacturing' declined 21% in the same period. Meanwhile the total workforce increased by 7.7%. Currently in the US unemployment is rising and there are reported shortages of workers with specific skill sets ranging from, for example, tool and die makers, machinists with CAD capabilities to more sophisticated technologies such as alternative energy systems, nuclear power and optoelectronics.

Looking at the Fortune 1000 group by industry sector, the 'Electrical, Electronics and Communications' companies, while having the highest numbers of employees in 'manufacturing,' broadly classified, up to 2000, then suffered a serious decline with the dot-com debacle and recovered steadily to being predominant through 2007. Unfortunately data for 2008 and projections for 2009 are not available, although there are current weak indications that there will be some recovery in this sector beginning 4Q 2009. On the other hand, earlier this century, the 'mechanical' sector, including aerospace as well as heavy equipment and automotive showed slight decline and stayed level through 2007 in second place. There is no doubt that the numbers for 2008 and 2009 will reveal a very significant decline resulting from global overproduction, and declining markets for the long lived and reliable products. In third place is the vastly profitable 'chemical' sector including petroleum-based industries, agriculture, food production and pharmaceuticals. These all comprise essential, competitive, commodities for populations that are gaining steadily increasing buying power globally. The workforce in this sector declined mildly through 2002 and has subsequently stayed level although with much increased productivity. Looking at the aggregated picture for all Fortune 1000 sectors representing 'manufacturing' total employment in 1996 was around 12 million, this rose unevenly to a peak of 13.8 million in 2000, followed by a decline to a low of 11.7 million for 2003 and thereafter a steady ascent to almost 13 million in 2007; the numbers for 2008 and 2009 will undoubtedly be somewhat lower.

Essaying projections beyond 2009 it is assumed, hopefully, that global prosperity will improve and that Fortune 1000 industries associated with manufacturing will benefit, thus creating greater revenues and more globally distributed jobs. The most efficient wholly US-based operations should also prosper as true costs and disadvantages of relying on third world labor become more apparent. Maintaining the final stages of production in close proximity to the largest markets should prove to be a viable future strategy. Growth in the 'Electronics, Electrical and Communications' industries and the associated technology areas should continue unabated but with the usual cyclical hiccups, mergers, and some bankruptcies. The whole arena of advanced technologies, and particularly energy related aspects, is singularly volatile and subject to rapid change plus sensitivity to governmental policies and incentive structures. Chemically-based industries are likely to expand to serve growing populations; similar trends should prevail across the mechanical sector, once the prevalent automotive over-production has been stabilized.

Concurrently as this is all happening there are shifting organizational trends that tend to reduce the numbers and sizes of larger corporations. Size is being recognized as a handicap inhibiting fast responsive decision making, increasing overhead burdens and diluting the focus on core competencies. Some major conglomerates seem able to evade these factors, but history shows that just a couple of years ago there were a total of 913 US enterprises with more than 10,000 employees and now there are 890, a drop of 2.5%. Out of the 5.9 million businesses in the US there are only 1795 with over five thousand employees.[5] This should cause reconsideration of 'standard' assumptions in some management texts that assume hierarchies of levels and well defined areas of responsibility. Smaller organizations with multiplexed responsibilities, ample communication, appreciable flexibility and teamwork are becoming the norm.[4]

Future Products, Systems and Living Conditions

IBM develops an annual projection of the five most likely innovations in the next five years. Most recently this espouses pervasive energy saving, intelligent health monitoring as opposed to illness remediation, a web with conversational ability, digital shopping assistants (Amazon approaches this already), and memory support will be on tap.[6] While this may seem self-serving towards IBM's business interests it is supported by items in the current media relating to the dominance of electronics, communication devices and information technology. Finance, notwithstanding the current issues, must play an increasing role requiring responsive global oversight to ensure free trade and with possibly limited protective tariffs warranted to 'level playing fields.'[1]

Future products can be divided into several categories mainly derived from our human needs that multiply as prosperity increases. Initially these included Food, Safety, Shelter, Clothing, but have grown to include matters like Transportation, Entertainment, Education, Recreation and the self-actualization gadgets that identify and differentiate us from our peers. Additionally as businesses focus on core competencies there are more opportunities for efficient sub-contractors, vendors and other enterprises to contribute to global supply chains, distribution centers, maintenance and services. Formerly these jobs were all counted as 'manufacturing' because the workforce was directly employed by the OEM, or original equipment manufacturer.

The migration globally from areas of low population density to populous mega-regions is an inescapable trend. Based on the history of the Industrial Revolution of the 18th and 19th centuries this can create larger markets with more jobs and greater prosperity, but only if managed appropriately. Given the floods of people in motion around the world this has become a major political challenge. Populations globally crave the imagined, and real, relative prosperity and freedoms of much of the developed world. Clearly from a viewpoint of sustainability, efficient and effective delivery and responsiveness to perceived needs most products and services should be realized close to the centroids of the predominant population centers and markets. Education and the provision of services for these masses are essential if world comity is to prevail. Even so, the availability of products and services to the more sparsely inhabited areas of the planet must not be neglected, here again some benevolent centralized oversight may be required.

There will be more focus on sustainability and recycling. Small, durable, long-lasting, frugal products should gradually become more acceptable as total life-cycle costs including energy use, carbon footprints and eventual retirement, recycling or remanufacturing costs are built into business models. The future will certainly bring electronics to the forefront augmenting all products such as including RFID tags on foodstuffs and vegetables etc. to ensure traceability. There will likely be modular, flexibly assembled transportation systems with 'On-Star' style communication and tracking systems to afford traffic control, collect tolls, etc.

The Future Workforce

The needs of the industrial workplace have changed appreciably during the last half-century, or so. Certainly industry structures and organizations have become 'leaner,' more integrated and much more highly focused on development and exploitation of 'core competencies,' the use of vendors and supply chains. Academia has heard repeatedly from task forces, learned committees and professional society findings[7] that cross-disciplinary abilities, communication skills, teamwork, appreciation of the business context, project planning, management and an awareness of international matters and cultures together with abilities to develop timely solutions addressing ambiguous problems are essential in the present and future workforce.[8]

Engineering involves working on constrained puzzles and solving problems. Today's problems are by their nature intrinsically cross- and inter-disciplinary embracing multiple aspects and technologies, business, economics and the societal milieu. Today many leading edge research programs are located at the boundaries and intersections of the older disciplines, but most K-12 and undergraduate education continues to be organized around the disciplinary structures extant fifty or sixty years ago with recent and continuing augmentations to accommodate developments in bioengineering, computer and environmental sciences. Certainly students put through the rigor of ABET-defined and structured curricula can survive and successfully solve problems in their future careers – but could they be prepared more efficiently and effectively?

Currently curricula are constrained by accreditation, fossilized bureaucratically run agencies and our disciplinary sub-divisions. All the most interesting challenges and opportunities today involve cross- or inter-disciplinary processes. We must give our students ambiguous and unstructured assignments that force them to become empowered innovative self-learners capable of comprehending the frontiers of their chosen sectors of knowledge.[9] Overall our academic and professional organizations tend to retain us in 'teaching silos' whereas what we should really be doing is guiding our students and empowering them to learn for themselves.

Olin College is among leaders in the development of a curriculum for the future.[10] Students work in teams on comprehensive 'real-world' engineering problems. There are no separate academic discipline-based departments, however, it is small-sized and answers to the true interpretation of 'collegial.' The first class graduated in 2008, degrees have customary titles. There is an emphasis on the context and relevance of the engineering problems tackled by the teams and examinations are open-book and moderated by a strong honor system. This could be a model for consideration. Some community colleges are also developing curricula aimed at transforming the skills of the technical workforce to more closely match future requirements of alternative energy systems including wind and solar.

There are some notable achievements in the K-12 arena. These range from the FIRST Robotics Competition[11] that gets High School teams excited about engineering to the 7th and 8th grade Future City Competition.[12] Middle school students work in teams to design, imagine and explain solutions to infrastructure problems for a city one hundred or more years in the future. They must make an accurate scale model using recycled materials, write abstracts, and an essay (the 2008 topic was 'Nanotechnology,' 2009 it was 'Water'). They also make a SimCity computer model and then deliver presentations and answer judges' questions spontaneously. Some school districts include this contest in the regular curriculum. Local, Regional and International competitions for individuals, such as the Intel Science Fair, are another outstanding opportunity for brighter students from more progressive schools to display their technological acumen.[13] In fact, there are many superior scholars in the K-12 ranks that merit more challenging and flexible curricula at the university level. The performance of students in projects of this type demonstrates not only their competency levels but also the value of experiencing integrated 'practical' cross-disciplinary design challenges. When math, chemistry and physics can be experienced as necessary components of engineering problem solving then what were often deemed boring, prescriptive and 'must pass' routine courses can become useful user-friendly tools if delivered within an appropriate context.

Taken broadly and philosophically engineering is about solving problems, designing, constructing and making 'stuff' that satisfies human needs and concurrently generates wealth without trauma – this whole process cycle must be treated as a core of a revised curriculum. There is need to contemplate engineering as a holistic process involving, for example, not just mechanically-based artifacts like lathes and milling machines, but also as integrated and inseparable from chemical, electrical, metallurgical, biologic and other aspects. Engineers must be enabled by their training, their curiosity and their learning to design, facilitate and implement a whole sequence of processes from concept to realization and end-of-life whereby atoms, molecules and aggregates of materials and other resources are integrated, divided, augmented, reacted, deposited, fermented, or otherwise transformed by all manner of processes into products and/or services that satisfy global customers and bring revenue. All this must be accomplished in an essentially trauma-free sustainable manner. There is a need for generic engineering education treating engineering as the truly liberal art for the future. This needs to become customary both globally, and in the US and should be pervasive from K-12 to post-graduate studies.

In Conclusion

What's the net? First, students must be encouraged to recognize that all engineering has a common base of solving problems, and that today it is an activity affected by global events. Secondly, there needs to be emphasis on the generic nature of the transformation processes that generate products of whatever scale (and including data-rich 'products' such as financial instruments, insurance policies, mortgages, software etc.). There is need for a 'process' focus for the whole life cycle from concept and design to customer satisfaction and end-of-life. Students must be empowered to appreciate and recognize global business trends, communication and cultural issues, engineering economics, logistics and to be capable of contributing and working in diverse teams. The learning imparted, or encouraged, should not be prescriptive but it should be flexibly adapted to the informed needs of every student (and of their future employers).

Of course, it has often been argued that 'education should prepare students for life' as opposed to teaching content related to future jobs or careers that may be unimaginable today. This is a valid paradigm, but endowing students with capability to earn a living, to be adaptable and flexible while generating prosperity for themselves and their community must receive serious attention.

Thomas Friedman summed up the vision of the new (and exciting) world in an Op-Ed piece in the New York Times on October 19, 2008, talking about the financial crisis:

"I suspect we will soon see the same happening in industry. And, once the smoke clears, I suspect we will find ourselves living in a world of globalization on steroids — a world in which key global economies are more intimately tied together than ever before.

It will be a world in which America will not be able to scratch its ear, let alone roll over in bed, without thinking about the impact on other countries and economies. And it will be a world in which multilateral diplomacy and regulation will no longer be a choice. It will be a reality and a necessity. We are all partners now."

Recent speeches by President Obama have stated an objective of achieving a population with an increasing proportion of university graduates with an ability to generate greater prosperity by 2020. Closer to the present it is estimated in the press that "*significant numbers of jobs will be created, or saved, by the stimulus packages.*" However, "*out of possible 3.7 million jobs 54% will require a post-secondary certificate, and 37% an associate degree or greater.*" In fact, future prosperity has a heavy dependence on overall improvement in technological literacy. In the future there is need, not only for more engineers, but a higher proportion of the population with appreciation for the ramifications of energy, conservation, transportation and health issues.

Nevertheless, through this decade or so the US will likely remain the world's greatest consumer, the greatest and most rapidly responsive marketplace; additionally we have the ability and systems to become the leaders in solving many of the problems which may presently seem dire. Collaboration, flexibility, imagination and engineering ingenuity in response to the needs of global customers will to some extent level economic playing fields and there should be decent opportunities for all those countries and individuals with freedom, financially sound institutions and solid educational foundations. Times like the present afford excellent opportunities to initiate major changes with dramatic transformations of educational systems. Change must be embraced and with enthusiasm to survive, succeed, share rising global prosperity and reduce poverty.

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