**Engineering Education OR Just Education**

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Abstract

"Engineering Education for the Next Decade," but let's stretch and think farther out. Various national and international projections address 2030 and even 2050. Think of 2030, two decades will have flown by, or looking back we may reflect on 1990. Times were very different then and will likely be even more different in the future. Today there are new companies, new 'toys,' high technology cellular devices, marvelous digital cameras, and politically significant social movements all catalyzed by these innovations. Have our educational methods changed in parallel?

What of 2031? The US will likely no longer be a primary 'top-of-the-heap' nation; what is the U.S. prognosis? In particular, education practices have not experienced major curricula rearrangements since the traumas of Sputnik. U.S. science, technology, engineering and mathematics (STEM) rankings are below world-class. Our students today are rather different animals than those of just a few decades ago.

It is time to re-assess what is required of the engineering education community. Industry groups are continually lamenting "critical skills shortages" and it is obvious from the levels of rhetoric in Washington and our media that there are major and persisting deficiencies in our broader education systems. Current topical debates reveal woeful levels of scientific and technological illiteracy leading to the conclusion that a high priority is not necessarily the improvement of 'engineering education' but a major overhaul of the entire system to match productivity demands that will be placed on our future workforce. The need for dramatic change is explored.

Introduction

Aerospace, automotive and energy industries are exceptionally busy making forecasts out to 2030 and even, in some cases, to 2050. In fact, the bulk of their products possess remarkably lengthy life cycles customarily accompanied by Greenhouse Gas (GHG) emissions. So as we consider engineering education for the next decade, why not stretch and aim our discussions and projections for a couple of decades or more? Where will our nation and the world be in 2031? What will be the issues, opportunities, pressure points, problems, requiring our best engineering solutions both nationally and globally over this horizon? The engineers that we are educating today should be engaged in the productive periods of their careers. What should we be doing today to prepare them adequately to conquer the manifold challenges that their world will face? How may these challenges differ from those of today, and how should their preparation be adjusted?

## Appreciating the Recent Past

Before projecting forward into the imaginative postulated worlds of the likes of Huxley, Verne, Vonnegut and Wells, to name but a few, it is wise to glance backwards. The United States today is thought of as among the ranks of the most productive and prosperous nations on the planet. In 1990; the United States population was 249.6 million (313.2 M today). Tim Berners-Lee was developing the principles for the internet; Amazon, Facebook and Google were hardly thought of, the Dow was below 2700 (now over 11,000) and Boeing was in the throes of developing the 777. Today we have many new companies, new 'toys,' high technology cellular telephones and personal digital assistants (PDAs) that are becoming 'smart' enough to communicate emotions, marvelous digital cameras, 'cloud' computing and politically significant social movements catalyzed by many of these innovations. As a nation we also possess many problems, not forgetting a frequent plea for greater skills, and more especially 'soft skills' in the workforce.

One of the first steps in assessing any problem is to discover analogs and establish benchmarks.
How are other nations performing and dealing with similar problems although possibly with different cultural, economic and social constraints and customs? Following very many searches a massive array of data was assembled. Factors such as 'Quality-of-Life,' 'Ease of Doing Business,' various governmental expenditures expressed as a percentage of 'Gross Domestic Product (GDP) per capita,' and, importantly engineering graduation rates. A commendable approach by 'The Economist' drew attention early in this research – "The World in 2005, Quality-of-Life index – The Economist Intelligence Unit's quality-of-life index."[1] Unfortunately this is now six years old, but so far, no successor report has become available from this source. This then was a starting point; using other data sources a list of ten countries with some affinities, relevance or similarities etc. with the United States was established. This was augmented more recently with input on the increasingly prosperous BRIC countries, Brazil, Russia, India and China. Primary sources for this data were OECD (Organization for Economic Co-operation and Development) web sites and the CIA Fact Book.[2, 3]

## Comparative Prosperity

There are many ways for ranking countries and a confusion of data is available. "The Economist" offers a 'quality-of-life' index with the most recently available tabulation dating to 2005 that places pre-crash Ireland at the top with a score of 8.333 on a scale of 10. Switzerland, Norway, Luxembourg and Sweden follow closely. The United States earns a score of 7.615 and thirteenth position with Canada and New Zealand next. The BRIC group enters this list with Brazil (39/6.470), China (60/6.083), India (73/5.759) and Russia (105/4.796).[1] The scoring system attempts to go beyond relatively straightforward GDP including points for such factors as community life, family life, gender equality, material wellbeing, political freedom, and similar possibly culturally determined statistics

An alternative tabulation for 183 countries is published by the World Bank which ranks economies according to the 'Ease of Doing Business.' For June 2010 Singapore was top, followed in rank by Hong Kong, New Zealand, United Kingdom, United States and Denmark; Ireland is ninth, Japan eighteenth, and Germany twenty-second. China is seventy-ninth one place ahead of Italy, Russia one hundred and twenty-third, Brazil one hundred and twenty-seven, and India one hundred and thirty-fourth.[4]

A surprise resource that also provided more insights and possible confusion was found in a magazine aimed at future emigrants called "International Living."[5] A complex scoring system rates countries based upon 'Cost of Living,' 'Leisure & Culture,' 'Economy,' 'Environment,' 'Health,' Infrastructure,' 'Risk & Safety,' etc. giving a rank and final score. Many countries in the developed world gained closely similar scores, but the Less Developed Countries (LDCs) are shown up significantly. Table 1 shows this list of fifteen countries ranked by the 2005 'QoL' and showing population, GDP per capita, ease of doing business ratings and the number of companies featured in the top one hundred from the Fortune Global 500 listing.[6] This latter factor and the GDP figures add re-assurance for the United States, and confirm our present strengths. GDP figures are for 2010 based on the CIA Fact Book.[3]

| Qual.Life Rank (1) | **TABLE ONE** Country | Population | 2010 GDP $ (3) per cap | 2010 Global Co's (6) | Business Ease Rank (4) | Internat. Qual.Life Score (5) | Living Qual.Life Rank (5) |
|---|---|---|---|---|---|---|---|
| 1 | Ireland | 4,670,976 | 37,300 | | 9 | 70 | 41 |
| 2 | Switzerland | 7,639,961 | 42,600 | 2 | 27 | 81 | 3 |
| 6 | Australia | 21,766,711 | 41,000 | | 10 | 81 | 2 |
| 13 | USA | 313,232,044 | 47,200 | 29 | 5 | 78 | 7 |
| 14 | Canada | 34,030,589 | 39,400 | | 7 | 72 | 9 |
| 15 | New Zealand | 4,290,347 | 27,700 | | 3 | 79 | 5 |
| 17 | Japan | 126,475,664 | 34,000 | 11 | 18 | 70 | 36 |
| 25 | France | 65,312,249 | 33,100 | 10 | 26 | 82 | 1 |
| 26 | Germany | 81,471,834 | 35,700 | 11 | 22 | 81 | 4 |
| 29 | UK | 62,698,362 | 34,800 | 8 | 4 | 73 | 25 |
| 30 | S. Korea | 48,754,657 | 30,000 | 3 | 16 | 69 | 42 |
| 39 | Brazil | 203,429,773 | 10,800 | 1 | 127 | 70 | 38 |
| 60 | China | 1,336,718,015 | 7,600 | 6 | 79 | 56 | 97 |
| 73 | India | 1,189,172,906 | 3,500 | | 134 | 58 | 88 |
| 105 | Russia | 138,739,892 | 15,900 | 2 | 123 | 54 | 111 |
| | AVERAGES | 242,560,265 | 29,373 | | | 71.6 | |

The table shows some good news upon which to base future optimism about the United States. Among the 'Global 500' companies listed by Fortune magazine by revenues for 2010 there are 29 in the top one hundred with US headquarters addresses, Germany and Japan rank next with just eleven apiece, France follows at 10, Britain with 8 and China 6. However when we examine an 'Industry Week'[7] list of the top one thousand publicly held manufacturing companies ranked by revenues for 2010/11 we find 37 Euro-based companies (inc. Russia), 31 in Asia (inc. Australia), and just 31 in the Americas (inc. Brazil). The operations in the 'Petroleum & Coal Products' category are strongly represented among those with highest revenues, with 'Electrical Equipment & Appliances' balancing 'Motor Vehicles' as next in line numerically. This doesn't augur well for efforts to reduce carbon emissions (But then horse manure was allegedly a very huge issue at the start of the last century).

Commercially then we can conclude that the US is trading alongside industrial operations that are approaching, or have reached some level of parity. Nationally we may not be the economically, or industrially healthiest 'fish in the ocean,' but we rank very highly among countries that maybe striving to join us as peers. In fact, nations and their hegemonies are being superseded by conglomerates, and multinationals. Already Wal-Mart has more employees than many smaller member countries of the United Nations. The Gross Domestic Product (GDP) of several US cities and states exceeds that of many small nations. Competitors and emulators are arriving at the global table – commerce and international trade can only increase (along with population). It is worth noting that the 'Industry Week' tabulation gives no indication of degrees of governmental control or investment in their respective national 'industrial treasures.'

Engineering Education

Expressed simply a nation's prosperity ultimately depends on what it grows, makes or mines – this has been largely de-emphasized in many western countries. Agri-businesses have flourished, along with genetically modified (GM) or engineered (GE) developments affecting both high volume crops and the mass-processing of animals and fish. Manufacturing in many countries has been diminished, but is now tending to be recognized as a necessary component to provide jobs, prosperity and wealth generation.[8] Education and the nurture of a skilled workforce are of vital importance. Table 2 displays the record for the fifteen countries based upon OECD data (plus the most recent data from the 'Programme for International Student Assessment (PISA)). [2]

| **EDUCATION** | **TABLE TWO** | | | | Higher | Educ. $ | Ranks | | |
|---|---|---|---|---|---|---|---|---|---|
| Sorted by % of Engr Degrees in total of all degrees | | | | | Ed. % | % GDP | OECD | PISA | Ref. 2 |
| Rank | | All Degrees | Engr.Degr. | Engr.% | Pop. | 2007 | Math | Science | Reading |
| 60 | China | 1,726,674 | 575,634 | 33.3 | 0.13 | 3.3 | 1 | 1 | 1 |
| 30 | S. Korea | 270,546 | 68,601 | 25.4 | 0.55 | 7.0 | 4 | 6 | 2 |
| 17 | Japan | 558,184 | 96,675 | 17.3 | 0.44 | 4.9 | 9 | 5 | 8 |
| 25 | France | 285,238 | 39,409 | 13.8 | 0.44 | 6.0 | 22 | 27 | 22 |
| 26 | Germany | 267,597 | 34,207 | 12.8 | 0.33 | 4.7 | 16 | 16 | 20 |
| 2 | Switzerland | 25,254 | 3,056 | 12.1 | 0.33 | 5.5 | 8 | 15 | 14 |
| 105 | Russia | 1,335,528 | 134,392 | 10.1 | 0.96 | 7.4 | n/a | n/a | n/a |
| 1 | Ireland | 25,865 | 2,544 | 9.8 | 0.55 | 4.7 | n/a | 20 | 21 |
| 6 | Australia | 171,582 | 12,357 | 7.2 | 0.79 | 5.2 | 15 | 10 | 9 |
| 14 | Canada | 176,910 | 12,369 | 7.0 | 0.52 | 6.1 | 10 | 8 | 6 |
| 29 | UK | 319,260 | 19,900 | 6.2 | 0.51 | 5.8 | 28 | 16 | 25 |
| 15 | New Zealand | 31,737 | 1,939 | 6.1 | 0.74 | 5.9 | 13 | 7 | 7 |
| 39 | Brazil | 677,154 | 31,953 | 4.7 | 0.33 | 5.2 | n/a | n/a | n/a |
| 13 | USA | 1,502,922 | 68,227 | 4.5 | 0.48 | 7.6 | 30 | 23 | 17 |
| 73 | India | 750,000 | 29,000 | 3.9 | 0.06 | 3.3 | n/a | n/a | n/a |
| | | | | Average | | 5.5 | | | |

The deficiencies of the United States with respect to STEM (Science, Technology, Engineering and Mathematics) education is revealed with embarrassing clarity. As a partial compensation the results for China are admittedly from restricted testing in Shanghai and other major cities and do not represent the whole country. Additionally, to some extent, it may be misleading to quote costs as percentages of GDP per capita; these numbers are greatly affected by population and social factors. Nevertheless, it is valid to compare numbers of engineering degrees as a percentage of all degrees granted, and of the fraction of these 'engineers' as a proportion of the whole population. The published rankings and scores in respected international surveys are also inarguable. The United States vaunted strengths in education, and our degree granting institutions is not reflected by the numbers. Percentage of engineering degrees for 2006 (or more recent year) per OECD[2] among all other degrees show China at 33%, S. Korea 25%, Japan 17%, France and Germany with above 12%, Russia 10% and the United States 4.5% next to Brazil and just above India 3.9%. Another column shows the percentage of the whole population securing degrees, the US at 0.48% is not very different from similar countries, whereas China's multitudes count 0.13%

Healthcare

An important component of prosperity and quality-of-life is healthcare, here there are large differences between costs and results across different countries' systems. The United States leads in both proportion of GDP devoted to healthcare at 17.4%, re-expressed as $7960 per capita accompanied by life expectancy at birth of 78.2 years; whereas Germany is shown at 11.6%, $4218 and 80.3 years. Table 3 shows the data collected by OECD for 2009.[2] Another source, The Economist[9] offers a more recent narrative in an article published in March, 2011. Figure 1 shows that Chileans enjoy similar life expectancy at birth as do Americans, this is some four years less than the Japanese but with large differences in costs per person. Seventy years ago in 1940 the health of Americans was superior to that of war-ravaged Europeans – the average 65-year-old male had a life expectancy of 12 years to just 77. In the UK and France comparable figures were respectively 11 and 10 years. For 2011 the expectancies are France 18 years, with UK and US at 17 years.

| HEALTH OUTCOMES | | TABLE THREE | | | Int.Liv. |
|---|---|---|---|---|---|
| Qual. Life Rank (1) | Country | % GDP Health (2) | Health $'s/cap. | Life exp. birth (2) | Qual. Life Rank (5) |
| 13 | USA | 17.4 | 7960 | 78.2 | 7 |
| 25 | France | 11.8 | 3978 | 81.0 | 1 |
| 26 | Germany | 11.6 | 4218 | 80.3 | 4 |
| 2 | Switzerland | 11.4 | 5144 | 82.3 | 3 |
| 14 | Canada | 11.4 | 4363 | ~80 | 9 |
| 15 | New Zealand | 10.3 | 2983 | 80.8 | 5 |
| 29 | UK | 9.8 | 3487 | 80.4 | 25 |
| 1 | Ireland | 9.5 | 3781 | 80.0 | 41 |
| 6 | Australia | ~8.7+ | ~3600 | 81.6 | 2 |
| 17 | Japan | ~8.5 | ~2878 | ~83 | 36 |
| 39 | Brazil | 7.5 | n/a | 72.5 | 38 |
| 30 | S. Korea | 7.0 | 1980 | ~80.3 | 42 |
| 105 | Russia | 5.3 | n/a | 66.3 | 111 |
| 73 | India | 4.9 | n/a | 66.8 | 88 |
| 60 | China | 4.5 | n/a | 74.7 | 97 |

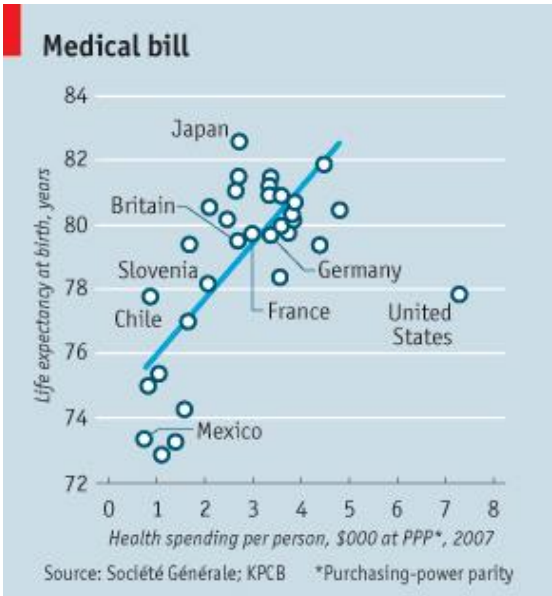


Figure 1 (Ref. (9))

"Health costs and life expectancy," from 'The Economist,' blog Mar 3rd 2011

## Logistics

Logistics are of critical importance in a globally competitive marketplace. Transporting goods, materials and products in 'standardized' containers started slowly in America in the fifties and did not blossom internationally until 1966 with service from the US to Rotterdam. Today 90% of non-bulk cargo travels in containers.[10] Looking outward from the US there is perception that the US trades vigorously with China and that shipload after shipload reaches US ports full of Chinese and other Asian manufactured goods. US trade with Asian countries is vigorous, but it must be realized that inter-Asian trade is of much greater volume, Table 4 shows that there are high volumes of business involving countries other than North America. Nationally we remain a very important factor, intermediary, designer, manufacturer, coordinator, consumer, and possess very many niche areas of global commerce. Our systems and initiatives are copied and envied but we must recognize ourselves that we are not necessarily any longer the world's best, the greatest, the 'mostest' etc. It needs to be emphasized that there is an appreciable volume of global commerce and trade outside North America. Certainly much of it likely involves US-based multinationals that may repatriate some revenues. Companies such as GM are on the threshold of producing more cars in China than they do in the U.S. or Europe. Thus, nationally we rank highly in many areas but there are many countries that we can learn from.

| **TABLE FOUR** Ref (10) | 2009 |
|---|---|
| Intercontinental Container Traffic | |
| Intra - Asia | 44.0 |
| Asia - N. America | 11.5 |
| Asia - Europe | 11.5 |
| N. America - Asia | 6.5 |
| Europe - Asia | 5.4 |
| Intra - Europe | 7.0 |
| "20-foot" equivalent units (Millions) | |

Discussion

Just as the details and subtleties of 2011 problems could hardly be contemplated twenty years ago, we should forswear any notion of defining future problems aside from those that are already, and rapidly becoming apparent. We must accept ambiguity and prepare our students to be problem solving intellectual and pragmatic 'commandoes.' Notably both today and in the future the United States will not necessarily remain as a solitary primary 'top-of-heap' nation. Notwithstanding this our gross domestic product (GDP) is the highest in the World per capita at $47.2K; almost 10% greater than second place Switzerland. Our relative prosperity is declining slowly, our exports still rank highly thanks to aerospace, agriculture and silicon valley (to simplify), and imports flow almost without pause. Our quality-of-life rates lower than several nations in Europe, our healthcare expenditures are the highest in the world but give us less than stellar results on a per capita basis, and education statistics present a similarly depressing picture.

On the education front, the US possesses many of the most vaunted institutions in the World and our curricula, accreditation procedures and concomitant research output are envied. Our system also continues to attract many foreign students notwithstanding high costs, accompanied by immigration, language and logistical barriers. But nevertheless industry leaders cannot find employees with the special skills and background knowledge that are required in the 21st century workplace. There are claimed deficiencies in "soft skills." This is not unlike some of the acknowledged deficiencies in the engineering workforce in the late seventies and early eighties. Here the issues were defined by many task forces as requiring a broadening of the engineering curricula to include communication, business knowledge, teamwork abilities and IT competencies.[11]

Subsequently this 'laundry list' has been augmented as result of competitive pressures globally to include consideration of cultural and international factors. Many degree programs have developed compensatory 'minors,' cross- or inter-disciplinary options and graduate programs; these are exemplified at Lehigh with the cross-disciplinary graduate program leading to an MS in Manufacturing Systems Engineering that first welcomed students in 1984 and is now available on-line, and an Integrated Product Development Program with both graduate and undergraduate sections.[12,13]

Collaborative working in teams was a feature of the IBM Manufacturing Technology Institute that was established in Manhattan in 1981 to revitalize the old-style IBM manufacturing workforce.[12] During the next decade teamwork started to become a feature of the K-12 curriculum and several competitions such as FIRST (**F**or **I**nspiration and **R**ecognition of **S**cience and **T**echnology) for 9-12 grades in 1992, and a Future City Program for 6-8 grades in 1993 were inspired.[14] The imaginative and innovative skills that are unleashed in contests of these types should not be suffocated (and destroyed) by excessively prescriptive curricula. By 2000 teamwork was becoming pervasive in some few engineering courses and at several levels.

Overall subsequent improvement efforts have mostly amounted to tweaking what we have, packing more content into limited time and only really catering for students willing to explore topics beyond the customary disciplinary boxes and 'silos.' Sir Ken Robinson[15] explores the fossilization of our curricula structure with persuasive rhetoric in YouTube pieces, on TED and convincingly in his book "Out of Our Minds." There is a need to step back, absorb the changes in communication, contexts, habits and available technologies to totally restructure curricula so as to equip our students to enter the contemporary and likely future workplace. Our students today are rather different animals than those of just a few decades ago. Admittedly, though, good students can survive our existing prescriptive curricula and become excellent contributors; but it is reasonable to postulate alternative approaches that may increase our STEM population.

Summarizing

It is worth reflecting on the ideas of Confucius/Xun Xi in 450 B.C. and striving to place greater reliance on Project-Based (or 'experiential') Learning (PBL):
*"Tell me, and I will forget. Show me, and I may remember. Involve me, and I will understand."*
Senior Design projects seem satisfactory for students that survive to become seniors. However, if the whole curriculum could be inverted to offer major ambiguous exciting design and research projects to first year students then the boring rigors of 'standard or routine' courses would possibly be more readily tolerated. Preferably though it could be found possible to deliver learning modules as needed with sufficient content to solve problems and detail issues as they arise and thus afford significant 'active' learning experiences.

Our existing curriculum structure can be traced back to the industrial revolution, this age also stimulated the growth of unions and guilds. Our industrial activities became more complex, content, standards, constraints and a variety of organizational and management techniques developed. Technologies grew in parallel; the individual slate and chalk was superseded by paper and pencil, blackboards and movie clips by Power Point, and YouTube. In the main content remained prescriptive, standardized and was augmented, trimmed, expanded to mention latest trends: And also most importantly to conform to the requirements of accreditation, the professional silos and the US News and World Report rankings. Efforts to innovate academically are doomed to only partial success when constrained by standardization, and discipline-related habits and thought processes.[8]

Prior papers delivered to ASEE Regional conferences have discussed curriculum development at length.[8] These can be summarized briefly as defining a need to think 'outside the box' and starting again with a redefinition of the education problem and understanding of the differences in technologies and society in the last three decades and more. Sir Ken Robinson presents these ideas most eloquently and repetition would be redundant.[15] What has to be addressed are the organizational barriers to starting these processes and their implementation. As individuals we can empower students in our own classrooms, and digitally, to handle ambiguous 'open-ended' challenges, but there is need for wider and more systemic adoption of these approaches. There are some remarkable contrasts between the United States and all of the countries tabulated above that we can learn from. In particular, the example of Germany is worthy of deep contemplation. Overall they seem worthy of some emulation in their regard for science, technology, social welfare, and other factors.[16] Their economy may be of some concern, but then whose isn't?

In the United States in 2011 our collective imaginations are also severely constrained not only by the aforementioned factors but by an evident and woeful deficiency in the levels of scientific and technological awareness of the administrators, communicators, politicians and leaders of our communities – in short by ourselves.[17] We are, as a society, collectively and willfully ignorant, unable to accept, appreciate or understand what could be accomplished by overall utilization of sane applied science and sustainability objectives. Our media, in the main, collaborate in exacerbating these problems in the interests of satisfying their advertisers (who provide much of their revenues). Are we trapped? No! Forums like this – discussions among ourselves and in our individual classes will eventually bring some ameliorating changes. However, our students will face the problems that we knowingly leave behind and they will be solved albeit belatedly. The 'sky is not falling' – not quite yet; but there is need for strict logical and science-based management of global resources, particularly with respect to food and water, carbon-footprints, infrastructure, sustainability and all the problems and discoveries that all these issues entrain. The future is bright with promise and possibilities, but realization may bring some discomforts as a global and pervasive economic social thermodynamic evolution takes place.

## Conclusions

What is the prognosis for the United States? Overall the tabulated data shows that the U.S. is no longer the pre-eminent world leader and example that was often imagined. Nevertheless our major multi- national enterprises are among the leaders of globalization and many receive a major proportion of their revenues from off-shore. They are providing jobs, increasing market share and enhancing prosperity globally. Meanwhile on the home front education, healthcare and many intangible quality-of-life factors are not producing results at levels befitting our aspirations, or reputation.

Thus, we should not focus our concerns solely on 'engineering education' but on developing an education paradigm whereby engineering, science and appreciation for modern technologies are pervasive throughout the population and embedded and respected as true 'liberal arts.' [16]

Changing our collective approach to education at all levels is an important objective. Middle school age kids have fertile imaginations, they can be most imaginative and innovative as shown by many competitions. Our whole pedagogical structure must be enlivened and enriched to provide an educational regime that will awaken and satisfy the natural scientific curiosity of these future students and citizens. Concomitantly we must collectively challenge the current abysmal scientific and technological competencies of our whole society and stimulate 'moon landing-type' levels of excitement, interest and understanding throughout our citizenry. We must make these efforts throughout our academic structures and escape our silo-boxes that we so willingly shelter behind. The issues that we face are <u>education</u> overall and not just 'Engineering Education.'

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