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NORMAN AUGUSTINE PRESENTATION
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Norman Augustine is the former president of Lockheed Martin Corporation. He chaired the committee that produced the 2005 report "Rising Above the Gathering Storm" calling for more U.S. investment in science funding and education. He presented a symposium-wide planniery talk at the SPIE Defense, Security and Sensing symposium in April 2009. His talk was titled “Re-engineering Engineering.” Dr. Augustine is introduced by Dr. Ray Johnson, CTO and Senior Vice President of Lockheed Martin.

Good morning everybody my name is Ray Johnson, and I'd like to welcome you to the planniery session this morning. It's an honor and a privilege to introduce our key note speaker this morning, Norm Augustine.

Norm was raised in Colorado and attended Princeton University where he graduated with a BSE in Aeronautical Engineering Magna Cum Laude, and an MSE. He was elected to Phi Beta Kappa, Tau Beta Phi, and Sigma Chi.

In 1958 he joined the Douglas Aircraft Company in California where he worked as a research engineer, program manager, and chief engineer. Began in '65 he served as

-- in the office of the Secretary of Defense as the Assistant Director for Defense Research and Engineering. He joined LTV missiles, a space company, in 1970 serving as Vice President of Advanced Programs and Marketing. And in '73 he returned to the government as Assistant Secretary of the Army, and then later became Under Secretary of the Army and Acting Secretary of the Army. He joined Marin Marietta Corporation in 1977 as Vice President of Technical operations. He became CEO in 1987 and Chairman in 1988 having previously been president and COO. He served as president of Lockheed Martin Corporation upon the formation of that company in 1995, and became CEO later that year. He retired as chairman and CEO of Lockheed Martin in August of 1997 and at that time he became a lecturer with a rank of professor on the faculty of Princeton University where he served until July of 1999.

He was Chairman and Principal Officer of the American Red Cross for nine years, National Academy of Engineering President and Chairman of the Associate of the United -- Association of United States Army Aerospace Industry Association and Chairman of the Defense Science Board. He has been presented the National Medal of Technology by the President of the United States and received the Joints Chiefs of Staff Distinguished Public Service Award. He is a five-time recipient of the Department of Defense highest civilian award, the Distinguished Service Medal.

He is the co-author of a book that many in the room, I'm sure, know about "Augustine's Laws" and "Augustine's Travels," the follow-up. He holds 23 honorary degrees and was selected in who's who of American Library of Congress of the 50 great Americans.

Norm Augustine is a leader in industry, in government and academia. He's an author, a photographer, a world traveler, ladies and gentlemen the man who really needs no introduction, Norm Augustine.

Well, thank you Ray, and good morning ladies and gentlemen at this bright and early session. That was a very generous introduction and I now know how my friend David Roderick felt when he was chairman of US Steel and was introduced by someone who said that he was one of America's most gifted business persons. To prove it the master of ceremony had simply said that David had made ten million dollars in California oil. And when David came to the podium it was evident that he was somewhat embarrassed. He said, that truthfully it had not been California, it was Pennsylvania and actually it wasn't oil it was coal. And actually it wasn't ten million it was ten thousand, and it wasn't he it was his brother. And he didn't make it -- he lost it, so Ray thank you for that very generous introduction.

A slightly less flattering view of my carrier comes from a individual with whom you're probably familiar, Laurence Peter of the Peter Principle. I have never met Mr. Peter but I have a letter from him that I have framed on my wall at home that I treasure. Mr. Peter, after I wrote my first book wrote to me, and said that I had undermined his entire life's work that I had risen not one but two levels above my level of competence.

Whatever the case I am honored to join you once again at this conference which has certainly become one of the most significant of it's type anywhere in the world. And it's also nice to be back with so many friends and colleagues from the years past.

Although I have spent a portion of my career in the field of sensing and particularly optics, mostly in exoatmospheric discrimination, nuclear weapons detection, and land mine detection. I'm going to leave to others today to discuss the more esoteric aspects of that field and I plan to speak about a topic that -- of a broader nature.

One of the reasons for that is you may know I'm now in the fourth phase of my official career. You're probably familiar with those four phases. Phase one is when you're a co-author of technical papers. Phase two is when you're the principal author. Phase three is when you travel around the world presenting technical papers at invited conferences. Phase four is when you're invited to give the key note address for just to speak after dinner. And phase five is when you run around the world receiving awards and I'm not even going to go to phase six.

In keeping with that do let me take the big picture and begin with I'd like to turn the clock back a little bit. In fact, I'd like to turn it back about 200 million years. Now, my geologist friends tell me that something over 200 million years ago there was a super continent on this earth that made up of what today or a number of individual continents that were joined together was of course known as Gondwalaland. It included parts of what now would be Africa and South America, Australia, Antarctica, the Indian Peninsula, Arabia, and other pieces of land. At about that time the continent began to break apart, and all these elements moved considerable distance from each other began to have less and less impact on each other as they moved further apart.

But then my -- my economist friends tell me that -- that just the last couple of decades all these different pieces of land have come smashing back together and are firmly attached to each other in this new global world we live in. Kind of an amazing phenomenon where you have several hundred billion years of evolution basically reversed in a couple of decades where the impact on each other is greatly heightened once again.

Now, this phenomenon has been called the death of distance by Frances Cairncross who writes in the Economist. It's a very apt name I think and it's significance, of course, is that under many circumstances transactions to activities that used to require people to be in a close physical proximity of one another, don't require that anymore. People can be very far apart and conduct those same sort of transition -- transactions and they can even be in cyberspace together to do that. That means that almost anyone anywhere in the world can impact the lives of almost anyone else anywhere else in the world, and today what happens halfway around the world could affect us about seventy milliseconds later.

Bill Gates has observed that the internet will be to the 21st century what aviation was to the 20th century. Indeed the airline terminal does have a new companion namely the computer terminal. And in the most recent century it became practical to move objects and people, including people around the world at nearly the speed of sound at moderate cost. And, now, it's possible to move ideas, knowledge, information around the world literally at the speed of light and with extraordinary reliability and in fact the transmission stories of processing information, the cost of it is becoming negligible. This is an enormous change, of course, and as the saying goes "There's no longer a there out there, there is here and there is here now." The actions today then of a single rogue trader in Singapore can bring down one of London's most venerable banks, or the Shanghai Surprise can undermine the banks in the U.S. or the devaluation of the Russian ruble can bring down America's best-known hedge fund. Or as we've recently seen the sub-prime credit disaster in this country can cause Iceland to go bankrupt.

Tom Friedman in his wonderful books has a comment that globalization has accidentally made Beijing, Bangalore and Bethesda next-door neighbors, and the same certainly must be true of Ontario and Orlando. There are a lot of examples of the death of distance that we already see in our lives. For example, if a consumer in America wants to check on the status of their computer, a problem with their computer and to see what's wrong with it, or to make a reservation at the golf course, or to check their bank account, there's a good chance the person they speak with on the phone won't be here in America but they'll be in Puerto Rico or in Jamaica or in India. The extent to which this changes the world is suggested by the fact that in India today they teach courses on how to speak with a midwestern accident so that you'll be better suited to work at a call center.

And as an aside I have a neighbor who just recently was speaking with an individual in India and one of the things they teach in these courses is to take a western name so that people in America will be comfortable speaking with you. And this individual in India, my friend was talking to, absolutely insisted that his name was Abraham Lincoln.

I might share with you a recent experience I had in this idea of distance is dead. I was flying from Washington D.C. to Ithaca and the airline, which shall be nameless, lost my bag going to Ithaca. And then coming back the same airline, U.S. Air, lost my baggage going to Washington. When I got to Washington I went to the head of the baggage department and said that I'd lost my bags both ways, could he help me. And he said, no, you'll have to speak someone in Costa Rica to find your bags. So I called this individual in Costa Rica, who was very helpful, and his first comment was that he said that you must have gone through Philadelphia? And I said, well, yes, I had. It turned out this fella in Costa Rica was very insightful and he said you should know never to check your bags when you go through Philadelphia. I said, I didn't know that. And he said, yeah, there are only two kinds of bags in Philadelphia, carry-on and lost.

True story.

Another example of the death of distance is that if you get a CAT scan at a U.S. hospital there's a fairly good chance that it will be read by a radiologist in Australia or in Bangalore. In Washington D.C. today there's a company that has an office very near the White House, and if you go into their headquarters there you'll be greeted by a very pleasant woman who helps you with your appointments and handles access to the building and so on. But she's not sitting there in the lobby, she's on a flat screen display on the wall. She lives in -- in Pakistan, that's where she's at.

In 2001 there was a patient in Strasbourg, France, who had his gallbladder removed by a surgeon in New York remotely using sensing transmission and so on systems while the surgeon was still in New York. And as an engineer I've always hoped there was a back up surgeon in the room. Today, even the gestation of human babies is being off-shored, ethically arguable but nonetheless a practice that's taking place every day.

What has become increasingly apparent that the creation of new quality jobs in today's world is disproportionally dependent upon advancements in the fields of science and engineering, and indeed the creation of this global world that's bringing together again the continents is attributable to advancement in science and engineering.

In America it's basic research that creates the new knowledge, then it's engineering that takes that new knowledge and translates it into useful products and services. It's the working together of engineers and business people that takes those products and services then through entrepreneurship, introduces them into the market where they create jobs for other people, not engineers or scientists or business people.

Indeed the race for prosperity today is really a race for leadership in science and engineering. There have been eight different studies that I'm familiar with conducted in recent decades that have indicated that public investment in science and technology produces a societal rate of return of between 20 and 67 percent. There have been a number of other studies that have shown that somewhere between 50 and 85 percent of the growth in gross domestic product in this country in the last half century is attributable to advancements of science engineering. And the Federal Reserve Board concluded that about two thirds of the increase in productivity in this country in the last two decades is attributable to advancements in science and engineering.

It should, of course, be noted that it's not just the matter of maintaining a strong economy that depends on advancements in science and engineering. It also concerns many of the major problems that today, the challenges that face America and the rest of the world. These vary from the provision of energy to the maintain -- maintaining a livable environment to providing health care to providing food and water and assuring reasonable physical infrastructure to providing national defense, homeland security. Each of those is heavily dependant in their solution on science and engineering. And, in fact, if you think about it just a century ago the average life expectancy in America was 47 years, much of that advancement coming through science in particular.

What I suggest that we readdress the status of science and engineering in this country and particularly our source of science and engineers for the future. Alan Greenspan, when he ran the Fed said, and I quote, "If you don't solve the Kindergarten through 12th grade education problem, nothing else is going to matter all that much."

Producing more engineers of the type that we’re likely to need -- innovative, creative engineers -- is going to be a monumental challenge particularly given the hierarchical nature of an engineering or scientific education. And education where you can't take trigonometry until you've taken algebra and you can't take calculus until you've taken trigonometry, can't do complex variables until you've done calculus and so on. That's fairly unique if you think about it to most of the professions. What that really means is there's a decision point about 8th grade when a young person has to make a decision whether they want to preserve the option to become a scientist or an engineer. And there's a lot of empirical evidence that suggests that decision really gets made about 4th grade, when they either get turned on or turned off by a math or a science teacher.

Consider the task of producing one additional engineer, and the same with a PhD that can do very fundamental work in the field. Assume that that individual has completed the requisite courses during four years of high school and has successfully completed four years of undergraduate work in engineering in college. That now averages more than five years actually for most engineers. Then that individual's prepared to be in a six or seven year pursuit of a Ph.D and after that if they don't do post doc work, or whatever, they then presumably can launch into this career. There's also a lot of evidence that suggests that most the great innovation and science engineering occurs before a person is 45 years old, so there's a narrow window to hit there.

And indeed there's a great deal of leakage along this path to producing engineers, particularly engineers with PhDs. To begin with the U.S., about a third of the eighth graders never receive their high school diploma, of the ones that do about 40 percent don't go on to college at all. And of those who do go to college about half don't receive their degree, and of those who do receive a bachelor's degree over two thirds will not be in either science or engineering or mathematics. Under those -- those who are U.S. citizens and do receive a Bachelor's degree in either science or engineering or mathematics, only about one -- one in ten will go on to seek a Ph.D. Out of those who begin that core path toward doctoral degree about half give up along the way. And then once you get a Ph.D, about half of the Ph.Ds we produce, nearly half, decide to go on to some other field, law, or banking or what have you. Although I think may be changing at this point.

There -- I'm reminded of a story of the homeowner who called a plumber to fix a leaky pipe, and the plumber came, stayed about ten minutes walked out the door. As he went out the door he left a bill for 150 dollars. The homeowner followed him to the porch, said, my gosh, I can't believe that. He said, ten minutes work and 150 dollars, he said, that's more than I make and I'm a surgeon. And the plumber looked at him and said, yeah, that's more money than I used to make when I was a surgeon, too.

That's part of the problem that I think we face, but there are two edges to that sword. Consider the impact of technological advances throughout the years in just one field, let me pick the field of national security since many of us have worked in that area. There's a long history of cases where a single technological breakthrough had a major impact on the outcome of battle. You could go all the way back to the stirrup, the invention of the stirrup, or the long bow, or the -- the rifles or the machine gun or the tank or the airplane or the ballistic missile, nuclear weapons, night vision, stealth, computers, space. There's so much -- so many examples, those are just a few, where really the -- the path of the world changed because the outcome of battles that depended heavily on devices like those.

On the pace of advancement in science and technology, as everyone in this room knows, continues to accelerate. Craig Barrett, who was chairman of Intel, told me that on the last day of any given year 90 percent of the revenues at Intel receives that day are derived from products that didn't exist on the first day of that same year. And the point is that to stand still is to rapidly fall behind in the science and technology race.

So pervasive though are the fruits of science and technology that most Americans have come to take leadership for granted. This is an unfortunate outcome. Dan Golden, the former Administrator of NASA, tells a story that makes this point very well. It seems that Dan was conducting a town meeting and there was one individual at this meeting who was extremely critical of the amount of money that NASA was spending on Earth satellites. And this individual, this critic ended up his harangue by saying to Dan, for example, why do we need meteorological satellites; we have the weather channel? True story.

Today if you visit a modern semiconductor plant and contrast the integrated circuits that were produced many years ago with what comes out of that semiconductor plant the discrete devices, excuse me, of years ago with integrated circuits of today. The differences are enormous. Or compare the focal plane arrays that we have today with what I remember early in my career, we made them up of a few discrete elements. Or compare a plant today that makes optical fiber with one that used to make copper wire. Or in a different arena, go into a dentist office today and compare it with years ago. Or drive into a filling station today and compare it with before when a high-school kid would run out and fill your tank. Today you deal with smart gas pump, you wave a wand at the gas pump, it sends a signal 23,000 miles into space to a satellite that sends a signal back to a computer that checks to see if you're invested with Bernie Madoff or not and if you weren't it sends a signal back to the gas pump and says this person's okay, fill your tank, and then they send you a bill in the mail. An enormous change over time.

But now, in contrast let's go back some years ago and visit the average high school in the United States. You walk through a door into a room, there's some windows, there's some desks and there's a blackboard around the walls, and a teacher. Today, if you enter -- monitor a classroom in most schools in this country, there's a door and a room, some windows, some desks, a teacher, a black or white board around the wall, and that's about it. Really no difference in those two places.

And when you look at the way we teach engineering at an engineering school, the content over the years has changed enormously, unrecognizable. When I was a student the last chapter of our electrical engineering text book was about something called transistors. You contrast that enormous change over time with the way Pentium processor evolved and one is disappointed, I think, in finding how little the way we teach engineering has progressed. It's much the same as long ago.

So what I'd like to do is very quickly, and this is for you, what I think are 16 suggestions as to the way to appropriate content of an modern engineering education. This is based on my experience of witnessing 80,000 of my colleagues at Lockheed Martin who are engineers or scientists, and the experience of witnessing the students I taught who sometimes listen to me. I'd then like to close with a very audacious suggestion, and I won't attempt to address science education. I'm going to focus on engineering education but if you're interested in the applications I think one will find a good deal in common with what I have to say in the science education of that type.

Now, I'm sure there are people here saying Moses needed only ten suggestions, why does Augustine get 16? And I can only promise you that I will, in the words of George Steinbrenner whenever he hired a new manager, you know, he always said, "I won't keep you long." I will keep going.

I also realize it's not easy to change the traditional engineering education. As a former provost at MIT once told me when the two of us were working on an idea we had to try to change the one aspect of the engineering curriculum at MIT, our change cut across the traditional departmental structure. And this -- I was very disappointed, we weren't getting very far in spite of both of our efforts. I was a trustee there at the time. And finally this provost took me aside and he said, “Norm, the problem is that you just don't appreciate how difficult it is to overcome 100 years of excellence and success.”

Well, that's what I'm going to try to do this morning is to suggest ways to overcome 100 years of excellence and success, so that we can have another 100 years of the same.

So first the *sine qua non* of an engineering education for this next century, in my judgment, is going to be a very sound understanding of the fundamental laws of nature, physics, chemistry, and certainly an understanding of mathematics that's really the language of science and engineering. This underpins everything that science and engineers do if they hope to do it well. Unfortunately, even this knowledge changes from time to time. It's a little like the dean of medical schools at graduations traditionally stand up and say I have announcement that unfortunately I have to tell you that half of what we've taught you is wrong, and the problem is, we don't know which half.

When I was in college we were taught that there were three fundamental building blocks of nature protons, neutrons, and electrons. I don't recall anyone ever mention bosons and leptons and bottom quarks, and in fact we didn't even know the Higgs particle was missing. But to put it simply, to not know what is current is to unduly handicap a career.

Second, I believe it's very critical to teach the concepts of design and analysis, including parametric tradeoffs, and to have experience of putting those efforts into hardware; at some point to get one's hands dirty. And then to be involved in the work and testing and manufacturing ability, reliability, and maintainability and so on. And what I'm really saying there is that we should continue to teach engineering. Unfortunately, most of our schools don’t do a pretty good job of that today.

Third, it seems to me that it's time to address the circumstances whereby we lose to our profession over a third of the people who start in college to become engineers. One of the major reasons for their disappearance is said to be that the first year of an engineering program generally has nothing to do with engineering. You study math and physics and chemistry and maybe a couple of liberal arts courses, hopefully. But it's become almost a matter of pride or a rite of passage if you will for a third of the students to drop out, to be left behind. The old story about the dean look to the left and look to the right. We can't afford to do that in this world where we need good engineers and scientists, and many universities have tumbled to this fact and are trying to introduce programs in the Freshman year where you get some experience with what engineers really do, and how exciting it can be and how hands-on it can be.

Fourth, I think that every would-be engineer should be subjected to at least one course that examines the root causes of engineering errors, read “failures,” of the past. I was always amused when I get a phone call in the middle of the night that a rocket we had built had blown up on the way to Mars or something. The chief engineer would always begin by saying, this thing of course had exploded all over the sky, but the chief engineer would begin by saying “Norm, we've encountered an anomaly.” But there are a lot of lessons to be learned from those anomalies from the past. It might such a course could be called Scar Tissue 101, I think.

In participating in engineering failure analysis, and unfortunately in my career I had lots of opportunities to do that both in industry and in the government. I've never ceased to be amazed at how we learn the same lessons over and over. How much it costs in terms of tuition for the new generation of engineers to learn once again what the old generation paid to learn. For example, we've repeatedly learned that most failures of sophisticated systems are due to a combination of two failure modes as opposed to one. And very often the cause of that is that we assumed that the failure modes were independent when it turned out they weren't. In other words, redundancy only applies when the elements of that redundancy are truly independent. The Challenger would be an example. There are so many examples that we can learn from, the Challenger, the World Trade Center, the recent Interstate 35W bridge collapse, the old Kansas City Marriott walkway collapse. The ceiling tiles falling off the Big Dig tunnels, way back the Hindenburg crash, the Comet failures, the Tacoma Narrows Bridge, even the leaning Tower of Pisa. But I did have a student when I used to teach this in my course who raised his hand and asked, he said, how many tourists do you suppose would pay to go see the vertical tower of Pisa? There is a point to that, but we could save a lot of careers and a lot of taxpayer money, I think, if we could learn from some of these errors of the past.

That brings me to the fifth item, the need to expose students of engineering to the rudiments of systems engineering at the undergraduate level. One of the reasons for that is that so many of the advances in engineering today are occurring at the interfaces of different fields of engineering and science. And it's also at those interfaces where many of the problems we've encountered occur and so a familiarity with systems engineering would be extremely valuable.

Now, the problem in part is the definition of what is a system, and that's where many of the problems have their origin. The hydrogen atom is a system, so too is the universe a system, and the question is where are the bounds of the system that an individual is working on?

Systems engineers today are among the most sought-after in many industries but is a subject that very few universities even pretend to offer. I would also make the observation that most of the really good systems engineers I've known studied a specific field of engineering as undergraduates were exposed to system engineering but had their degree in a specific field and then did their graduate work in system engineering. Or worse yet, gained their systems experience through OJT (on-the-job training).

A sixth recommendation: the 21st century iteration of an engineer needs more emphasis on operations analysis and systems analysis with particular emphasis on probability and statistics. There are very few things engineers do that don't depend on the laws of probability. Miscalculations have led to more failures then one can imagine, and the same probably could be said of the tradeoff process that leads to requirements definition.

Seventh, there's an evolving demand for all engineers to possess at least a rudimentary knowledge of the modern bio sciences. Biology 20 years ago, at least to me, meant cutting up frogs and I figured we'd cut up enough frogs in this world. Today, it's a whole new world that interfaces closely with engineering in both directions. Certainly we couldn't have built modern medical imaging devices without the advance work of mathematics, electrical and mechanical engineering. Wouldn't have been able to sequence the human genome without the work that was conducted in robotics, mathematics, and computers. And in the other direction not likely that we would be able to produce fuels from bio sources without a good coupling of biology, chemistry, engineering, agriculture, and so forth.

And I make this prediction that biology and engineering will be become as hand in hand in the years ahead without much trepidation, although I realize that most predictions in engineering and science have been wrong. My favorite incidentally is one made by the inventor Alexander Lewyt, who ran the Lewyt Home Appliance Company some years ago, a fairly big company, and he made the prediction in 1955 as follows. I quote, "Nuclear powered vacuum cleaners will be reality within ten years." I think he missed that one.

Eighth, engineers have often suffered from insufficient understanding of economics. I mean just the fundamentals of economics, things like return on investment, internal rates of return, net present values, the appropriateness of capitalizing versus expensing costs, and the double edged effects of leverage and so forth. None of this is really rocket science but it has a huge impact on modern engineering and science. I would note in passing that the undergraduate degree held by most CEOs of Fortune 500 companies is engineering. And many of them, like myself, could have been much better equipped at economics then they tended to be.

Ninth, every engineer should pursue a course or otherwise be exposed to the subject of engineering ethics. And I'm not necessarily promoting a course in Socrates or Plato or Augustine or Kant or such, although that would be terrific, but I mean the real world down to earth issues that engineers run into that concern ethics. I'm always amazed at how many engineers believe that what they do has nothing to do with ethics. We deal with the laws of nature, they're immutable. What's that have to do with ethics?

Well, there are so many things that one runs into in life that deal with ethics and there's been one example that I used to like to use with my students. Would you think it was a good thing to introduce a product that would kill a quarter of million people every year, and most of my students would say no we should ban such a product. Well, then I would point out to them it's called the automobile. There are some very tough ethical decisions that engineers make along the way and ethics, unlike most other things in engineering, it's a little bit like launching rockets, there are no do-overs, no recalls, it's not like Detroit in that regard. The first rocket I worked on in my career for which I had any real responsibility blew up on the launching pad. Somehow my career recovered, on the other hand I've had too many friends who made one error in their life of an ethical nature and their career and their reputation never did recover. Good things to point out to students, it would have saved the world a lot of problems in recent years.

Tenth on my list, the so-called classical engineering education tends to be willfully void of courses in history, public policy, government, civics and so on. And increasingly engineers are being restrained building the things people want, not just the things that engineers want to build. The fact that you can build it doesn't mean that they will come. Think of the supersonic transport or the human trip to Mars or the superconducting supercollider, all were engineering tours de force, but none of them have happened. And as one who's testified before Congress probably 100 times in my life, there are a lot of people there who don't get excited about science and engineering just inherently, as many of us in this room, including myself, tend to do. And if engineers aren't willing to engage in the world of public policy and to speak out, and most of our elected officials are not engineers and scientists, then how are we going to make good decisions about these issues that affect our population in the world.

Eleventh, I couldn't offer a list of this type without commenting on the benefits of an engineering education of at least an exposure to the liberal arts, music, literature -- and art. And a few years ago I was giving a lecture at MIT and I was -- I'd been studying the requirements for a degree in mechanical engineering at MIT and I was complimenting the institute on the terrific set of requirements and I pointed out what they were. This was for mechanical engineering and in addition to the usual mechanical engineering courses that everyone would expect, the degree required of course the usual science and math, it had mandatory six semesters in either French or German, two semesters of English Literature, one semester each of rhetoric, English composition, U.S. history, European history, industrial history, political economics, business law, and economics of corporations. And after I'd profusely complimented MIT's leadership for this, I pointed out that MIT catalog I'd been reading was from the year 1900, which I'd found in their library. This may be a case where we have to go back to the past if we're going to move forward.

Twelfth, would observe that most of the engineers I've known were actually quite good engineers, and many of them were brilliant engineers. But, frankly, most had the uncanny ability to take a superb piece of engineering work and write it up in a fashion so it was absolutely incoherent. Engineers have really never accepted the idea that every sentence deserves a verb, for example. The two languages most engineers speak both have to do with programming computers -- neither concerns English. And that brings us to oral communications, but I think I won't even go there. I'm always amazed at proposals we've written at some of the statements that slip through our system that one wonders what in heaven's name we had in mind while we wrote those proposals, and those of you in the government on the receiving end of those know what I mean. About two weeks ago I saw a newspaper headline that obviously was written by an engineer who was talking about the management of FEMA, what is it, Federal Emergency Management Agency, I guess. And this particular headline said FEMA to move people in toxic trailers. Now, if you think about it I'm sure what they meant was they were going to take people who were now in toxic trailers and move them out, at least I hope that. That's not what the headline said, if you read it literally.

Thirteenth, recognizing that we're living in an era of big engineering. Those that wish to participate in such endeavors need to be expected to work as a part of a team, and need to have experience as working as part of a team. There are certainly important jobs yet to be done by the individual contributor, the Alexander Graham Bells and the Thomas Edisons, but increasingly engineers are going to find themselves working in large groups of people from diverse backgrounds and disciplines. More experience at team projects as part of the engineering education would be useful.

Fourteenth and most recently emerging attributes of an engineering project is that they often involve people from throughout the world and a semester spent abroad to become accustomed to living a different cultures with people of different backgrounds can be extremely valuable. My point is not that the second law of thermodynamics is different in the Orient from what it is in Orlando, but rather that the culture of applying the second law of thermodynamics may be very different. Today there are 200,000 individuals from China studying abroad, mostly in the field of science and engineering. The U.S. has nothing to compare with that.

Fifteenth, the emphasis particularly the laboratory work could be increased on innovation, entrepreneurship creativity and so forth. This of course has been a traditional advantage of the American education system particularly in comparison while many other countries. It's been said that you probably know the story that Penicillin is attributed to Sir Alexander Fleming. Having discovered that on a microscope slide he was working with that the bacteria were studying weren't drawing in the area where there was some mold that had accidentally contaminated the slide. And he took that idea and pursued it, innovated, it led to penicillin. It is said that, and I believe this to be true, that an engineer working at Raytheon on some of the early magnetrons noticed that a candy bar he had in his pocket was starting to melt and it lead to the idea of the radar oven, a microwave oven. It was the idea of being able to be an entrepreneur, innovative, to follow a new path that led to these and many other innovations we've seen. But going together hand in hand with this one has to be willing to accept occasional failure, not failure due to negligence or anything like that, but failure because every new idea doesn't work out. Harold Shapiro, the former president of Princeton, puts it, I think, extremely well. He said, "I do not recommend failure, nor am I attracted to the idea that failure builds character, but the willingness to accept the risk of failure is one of the costs of leadership and therefore the price of all progress."

And that brings me to the sixteenth and last item, and that is I realize I'm getting perilously close to the third rail with this suggestion, and that is I think we need to rebalance the emphasis at our universities on the part of the faculty between teaching and research. I'm well aware of the importance of research and the impact it has on teaching. Those of you who know me know there's probably no greater advocate of research then myself but I do think that at some Vernier correction, not a revolution, is needed to increase the emphasis placed on teaching as opposed to conducting research.

Well, that completes my list of what's needed to prepare an engineer to survive in the 21st century. It's a daunting list and it's only the beginning probably, one thing is that the modern practitioner of technology that stops learning when they get out of college will be professionally middle aged ten years later. Lifelong learning is essential, but importantly you may think that I don't realize that around suggestion number five, you started to say to yourself this all may be great stuff but where are you going to get the time to do this in four years, and the answer is you're not. It can't be done. And so my proposal is that the fundamental degree of engineering should be the master's degree, the entry degree. Most all the other professions require advanced work to enter the profession. Currently, it requires more than education to make a prescription to get a vaccination to my neighbor’s cat then it takes to design an airplane, which millions of people will fly, or to build a bridge which billions of people will cross. Simply stated it's time to recognize the master's degree is the entry degree of engineering.

While having reached the ends of my remarks and close to the end of our time I probably have not failed to gore the ox of at least everyone in the room one time. My view is that engineering is a wonderful career, certainly had a great impact on my life. I even met my wife when I was in engineering school. She still tells me that “the odds were good but the goods were odd.“

On the other hand if you list the challenges facing America and the world today, it's almost certain that it will be engineered not lawyers or accountants or bankers or politicians that solve those problems. And we should do everything we can to be sure that we properly have prepared our young people to become engineers in this period of turmoil. I'll close with a quote from Winston Churchill who said that "You can always count on the Americans to do the right thing after they've tried everything else." This one we need to get right the first time. Thank you very much.

Q. And, unfortunately, now as a professor I find that most people don't want to study outside their field, not only do they not want to study mechanical engineering as electrical engineers but even if they're doing electromagnetics, they don't want to have anything to with any processing. So I do not know how to energize the students in order to learn that you can try everything but unless the students want to see the benefit of that they won't, you know, they won't follow our -- our guidance. So I was wondering how could you -- what can industry and government do to help us faculty bring this fact to the students they have to be more broad based and not narrow based?

A. Your point is really a very good one, Ron, the -- and I think that problem will become more acute as time goes on because more and more of what we do you have to piece together knowledge of chemistry and physics and mechanical engineering, electrical engineering and so on. They're very few great discoveries that are going to be made purely in one field. I'm particularly struck by that, I serve on the advisory board to a company that's taking switch grass and turning it into fuel and into plastics. You look at the different kinds of skills that go into doing that, and the only thing I know to do since most students do have a greater interest in one field, which is I think to be expected, is they simply have to be convinced that if they want to make a living most of them are going to have to broaden themselves in terms of their knowledge of various fields. And part of that is -- comes from the fact that the teaching to making it more exciting in different fields and not the matter that, well, this week we got a new Maxwell's equations but try to make it more interesting and more exciting. And I've been struck, you know, and I was there at Amherst we used Maxwell's equations but we never realized that's what they were at the time we were using them. And there are these couplings that I think we could play on. Good question.

Q. Sir, outstanding presentation.

A. Thank you.

Q. I am here, I'm actually was once one of those elected officials referred to. I'm also not an engineer and if that isn't enough I'm speaking Thursday, my name is Jim Longley, I represent the Advanced Technical Intelligence Association. I want to pick up on what you said about the science and engineering in the United States. If anything you were very professional, yet from what I'm hearing the decline is precipitous, especially, with respect to how we stand relative to other countries around the world, and the trends are not at all positive. What efforts are underway that you might be aware of or should be underway to really confront this issue on the scale that you very artfully explained? It's critical to the nation's survival and our prosperity.

A. Well, you're exactly right. Just to quote a few statistics this early in the morning: Over the last two decades we now are graduating 20 percent fewer engineers then we were two decades ago with Bachelor's degrees, and this is a period of burgeoning science and technology. We're graduating 34 percent fewer U.S. citizens with Ph.Ds in engineering then we were two decades ago. We rank 16th among developed nations and the percent of our Bachelor's degrees that go to engineers or scientists, we rank 60th in terms of all nations in that measure. If you look at our scores in math and science I won't even get into that, but they're abysmal. We rank very near the bottom of the world class on average and so we have a very real problem that you point to, there's no question about it.

And the question, what are we doing about it? Actually there are some things being done, there needs to be a lot more. One of the biggest problems today is with young people, if you're in a U.S. school fifth or eighth grade there's a 69 percent chance your math teacher has neither a degree nor a certificate in math. There's a 91 percent chance your science teacher has neither a degree nor a certificate in science. How are they going to inspire you, interest you? The answer is they can't. So one of the things is being done in the stimulus package, I'm happy to say, is to try to produce more math and science teachers. If we had more time I could talk about how we're going to do that, but it's basically through scholarships that can be excited about understand math and science.

Turning to the other end of the spectrum showed I got an e-mail not long ago from George Heilmeier, who many of you remember used to run ARPA, ARPA it was I guess and George sent me this e-mail from Russia. He said, well, I'm in Russia; I always like to go to movies because in Russia the engineer always gets the girl. Addressing that issue, there's an effort underway at the National Academies right now working with Hollywood to produce a TV program somewhat in the vein of L.A. Law, I proposed it be called L.A. Engineer, I'm sure they won't do that. But in that idea of trying to show how exciting engineering can be in terms of solving crimes and solving technical failures and having real people that you could relate to doing these things. So there's some things underway but it takes time because you're starting with fourth graders really. Thank you.

I think we'll go ahead and end the questions right now. I want to thank all of you for attending. And I want to thank Norm. Please join me in thanking Norm for his presentation. Thank you.

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