What do Engineers Do, Anyway?
A talk by Paul Penfield, Jr.
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Hello, and welcome to this, the first of several "Last Lecture" talks here. I'm looking forward to hearing the others, and will try not to set too high a standard of excellence for the others to follow.

I did happen to notice that my abstract was the only one in the series which did not mention the word "health." I guess that means it is unhealthy, so please be forewarned.

Giving this "Last Lecture" is actually not too difficult for me, because I already had a similar opportunity. Not quite my last lecture, but one close to the end of my academic career. It happened that our department at MIT, Electrical Engineering and Computer Science, was founded in 1902 so of course we had a centennial in 2003 (as you can tell, we're not too good at simple math). As one of the few faculty with any sense of history, I was asked to give a "history of the department" talk which I entitled "The Electron and the Bit." I have a few DVDs of my 2003 talk if you are interested. That talk also formed the binding element of a centennial book, in the form of a series of seven short essays that cover different eras, important themes, and, of course, my own predictions for the future.

I found at that time that a convenient unifying thread was the changing role of engineers in the world -- what should they be expected to do --and the watershed events that led to changes in those expectations.

Today I will focus on those roles, rather than much of the history that is unique to our department. I will identify three major epochs, one being where we are today. Together with prehistory and the future, this makes five eras. So I will have four handouts (I told you we were not too good at math).

While the focus today will be on how things have changed, there are two facts that remain unchanged. First, we educators seem to be focused on a time span of 40 years. Why 40 years? Because that is the time of the career of a graduate, it is the year of retirement minus the year of graduation. Things that do not change much over 40 years can be regarded as constant. But if there are things that do change more rapidly, we need to equip our graduates to deal with those changes.

And second, there is the notion that engineers are defined by the degree programs they pursue. If you wonder what a civil engineer does, look at what they are taught in school. What does a physicist do? Look at the physics research degree programs. This was true a hundred years ago and it is true today. Because of this notion, if you are interested in what engineers are expected to do, as we are for this Last Lecture, you only need look at the degree programs and how they have changed over the years.

Now before we get started on this excursion into history, I have to say that I will focus on the branch of engineering that I know best, namely electrical engineering and, more recently, computer science. Other engineering disciplines have their own stories to tell, which may be different. Also, please be aware that the message is over-simplified in many ways -- a lot of detail is missing, though the essential points are there.

Pre-history (19th century)

So let's get under way. Let's not start in 1902, when our department was founded, or in 1882 when the nation's first electrical engineering degree program started, but 50 years earlier. There were no engineers. There were scientists, industrialists, and inventors. The leading electrical scientist in America was Joseph Henry, and he made magnets. The first industrial application of electricity was in, of all things, mining, to separate iron in the ore. A man named Allen Penfield owned an iron mine in Crown Point, NY. He got some magnets from Henry, and put them to good use. Thomas Davenport, a Vermont blacksmith, heard about them, came to visit, and was so impressed that he bought one from Penfield, trading his horse to get the money (so the story goes). He went back home and invented the electric motor. Although beaten to the punch by an Englishman by about six months, Davenport got a patent in 1837, No. 132, the first American patent ever issued for any electrical machine.

Henry did not think too much of the motor, mainly because the batteries of the day were too expensive and cumbersome. Electricity needed what would be known today as a killer app and the motor was not it. (A killer app is an application so compelling that people acquire the enabling technology just to run that application. You may remember that the killer app for personal computers was the spreadsheet, and the killer app for the Internet was e-mail.) But coming back to the motor, Henry was right. The motor was an invention before its time. But Henry understood what the killer app for electricity was -- it was the telegraph.

In 1844 Samuel Morse, who invented the Morse Code, the hand key, and other enabling apparatus, sent his famous message "WHAT HATH GOD WROUGHT" from Washington to Baltimore. Telegraph spread like wildfire. The public euphoria was similar to that of the Internet 150 years later.

Other electrical inventions came along. Edison'e electric light. Bell's telephone. And, using Davenport's motor backwards, electric generators for a central power plant. Even the electric grid. All this by 1882.

But there were no engineers. The inventors were basically tinkerers, without much scientific knowledge and essentially no training. That changed starting in 1882, when Charles Cross, professor of physics at MIT, started the nation's first electrical engineering degree program. The department of electrical engineering was established 20 years later.

Education for the Practice of Engineering, 1900 - 1950

So now we have the first electrical engineers. What were they expected to do? The practice of electrical engineering was defined by its degree programs.

MIT was fortunate to attract as an early department head Dugald Jackson from the University of Wisconsin. He was a clear thinker, with a no-nonsense approach to education. He knew just what was needed for the practice of engineering. He distinguished between technicians, who applied known technology, and engineers, who could develop new technology using known science, and scientists, who extended scientific knowledge. He called for four things in the engineering curriculum: communication skills, and knowledge of science, society, and business practices. In retrospect, we can see that his vision, which he articulated very well, was based on his understanding of the context at the time. The necessary science was available to the engineers who needed it; it changed slowly (compared to 40 years) so it only had to be taught once; it was known which sciences were needed and Jackson wrote the list; society changes slowly, and it is the job of technology to conform its creations to society. The result was an education valid for 40 years. The graduates were well suited for leadership in industry. The scientists of the day could be relied on to provide the underlying scientific knowledge in a form usable by engineers. There was one degree program, for people who wanted to be practicing engineers.

HANDOUT #1

It worked well. It really did. That is, until the context changed.

Engineering Science, 1950 - 1990

World War II ended in 1945. In the development of practical radar systems for the war effort, in the MIT Radiation Laboratory and elsewhere, it was discovered that the important and significant inventions were made by physicists, not engineers. That is, people with education in physics. Why? Dugald Jackson would not have expected that.

Look at the context. The necessary science was NOT in a form useful to engineers. Science changed FASTER so that what engineers learned in school was not enough. And the scope of technology was INCREASING -- engineers were asked to design different types of things, using different branches of science that they might not have studied.

Gordon Brown, another MIT department head, recognized the problem and provided the solution. In essense, he added to the list of jobs engineers should be able to do, the ability to develop new science appropriate for engineering. He called this engineering science. It differs from normal science only in the motivation for doing it. The normal motivation for scientists is curiosity, and engineering usefulness is a by-product. Thge motivation for engineering science was to support advances in engineering.

Brown rearranged the curriculum, and boosted the doctoral program since that is where people learn how to do scientific research. Not all students would go on for a doctorate, of course, so not all engineers would be able to do engineering science. But some would.

As a result, engineers would be responsible for their intellectual underpinnings, not having to rely on scientists. And there were now two degree programs for different types of engineers --

the bachelors for practice, and the doctors for research. Still nobody questioned the desirability for having the fruits of the engineering enterprise conform to society. At that time society was not changing rapidly.

HANDOUT #2

Brown's lead was copied across the nation. I am myself a product of that era, and I helped maintain it during my own career at MIT. It worked well. It really did. That is, until the context changed, in part by the very success of this paradigm.

Flexibility. The Current Era, 1990 - ????

In the mid 20th century electrical engineering education had to expand to include semiconductor devices and computer science. Not much was able to be discarded. As a result, here was too much material to teach. Both breadth and depth are important. Which should be sacrificed to accommodate the other? Students who wanted to get an engineering degree and then move into other fields did not need the depth, and they enjoyed the breadth of typical electrical engineering and computer science curricula. This might include those seeking a career in management, finance, law, or, most commonly, medicine. However, those interested in practice of engineering were not well served.

In other words, the context changed. Today, the scope of technology is much broader, and science changes very rapidly. And to make matters worse, society is also changing more rapidly, in part because it is making use of all the wonderful inventions of electrical engineers and computer scientists. Finally, it became apparent that before long engineers would need to know entire branches of science formerly irrelevant, for example biology or quantum mechanics. So not only was the scope of technology expanding, so was the scope of the required sciences.

Well, you can't do everything in a limited amount of time. So rather than sacrifice breadth or depth, our decision at MIT was to add a year, making our flagship degree program a five-year program. At the same time, we noted that the greatly increased diversity of society demanded that students be given greater flexibility so they could design their own set of specialties. If the student puts an extra year, there should be another degree. So was born the Master of Engineering degree program, designed for those seeking a career in engineering practice.

The result is now THREE degree programs -- the bachelors gives an engineering attitude and fundamental outlook to people going into a variety of careers. The master's degree is for those seeking practice. And the doctoral program remains for those interested in research.

Still it was the consensus that engineers should design so as to make their products conform to society, rather than the other way around. In fact, that was such an ingrained attitude that nobody even questioned it.

HANDOUT #3

It is still too early to tell if this approach is working. The Master of Engineering is very popular with students. It include an extra-breadth track (a mix of EE and CS) which is very popular. We have done a good job implementing things. The fact that the final two years can be seamlessly combined is a great help to students. However, other universities have not followed our department's lead. Even other MIT departments have not. We continue to believe that it was a good decision, but any structural change like adding a year, with the extra cost involved, is hard to justify. Time will tell.

Unfortunately, we may run out of time before the answer is known, because of another overwhelming change in context that is upon us. And this change will require a new responsibility for engineers.

Leadership. The Future.

What good is a look at history if you don't use it to say something about the future? In my talk in 2003 I did this in the form of advice to the next generation of professors, dealing with several detailed concepts. I'll leave those aside, however, and focus on the one change in society that I believe will be even more profound.

It has to do the role engineers should play in a changing society, and what we can contribute beyond the design of new gadgets, systems, or processes. And it comes back to the observation that so far it has always been accepted that technology should conform to society, rather than vice versa.

Let me explain.

Jackson's vision is 100 years old; Brown's is 50. Neither of them said that society needed help from engineers other than the normal engineering work product. To see why this may no longer be true, let's go back over 100 years, to 1893. The University of Wisconsin had only 61 professors. One was Dugald Jackson, who had just started their department of electrical engineering, and was destined to come to MIT ten years later. Another was the American historian Frederick Jackson Turner, who that year revolutionized the study of American history by proposing what later came to be called the Turner thesis, namely that the existence of America's western frontier was the fundamental dominating fact that had shaped the character of American people and the nature of its institutions. This quickly became the most important paradigm in the study of American history.

Jackson and Turner knew each other and had much in common. They were both articulate visionaries of their own fields, about the same age, with similar attitudes toward life and the university. They both moved to Cambridge about the same time, Jackson to MIT and Turner to Harvard.

Turner, the historian, must have known in 1893 that the American frontier was rapidly vanishing, but he might not have known what would replace it. It turned out to be a different kind of frontier, one that would be familiar to his colleague Dugald Jackson.

Now fast forward 50 years, to the second world war. Vannevar Bush was serving in Washington mobilizing the nations's technological enterprise in the war effort. Roosevelt asked him what would come next. Bush wrote a report called "Science: The Endless Frontier" in 1945, as the war was ending. In it he proposed a system of federal support for research, which would turn out to be crucial to the success of the engineering science paradigm for engineering education, that we have talked about. But what is interesting now is that word "Frontier." Yes, the scientific frontier has much of the same rough and tumble, exciting flavor as the Wild West. But more to the point, it has been enormously influential on America. Think of all the achievements in the 20th century made by engineering disciplines, especially electrical engineering and computer science. Electrification. Electronics. Radio. TV. Computers. Telephone. Automobile. Airplane. Agriculture mechanization. Refrigeration.

Although I am not a historian, let me suggest that the exploitation of the scientific frontier has done as much to shape America in the 20th century as the western frontier did in earlier times. The successor to the Turner thesis may be a similar one involving a different kind of frontier, the scientific frontier.

Bush called the scientific frontier "endless." But is it, really?

Well, there are certainly more exciting things to come. The information revolution is just starting and already the biological revolution seems inevitable. And engineers will continue to live and thrive on this frontier. But that doesn't mean it is endless.

Now life on the frontier is exciting. But most institutions in a civilized society demand more stability and predictability. Think about what happened to America's western frontier. Civilization arrived and brought with it law and order. For better or for worse the western frontier became a more predictable and less exciting place.

What about the scientific frontier? Will it have to become civilized?

I think so. Engineering is too important to society. Society cannot let it keep its chaotic, frantic character. This is already happening, as American institutions grapple with an onslaught of new technology which they only vaguely understand and often perceive as a threat. When new technology is thought to be disruptive, you can be sure there are powerful forces that will try to suppress it. That's one way of bringing law and order to the scientific frontier, but it is heavy-handed and discourages further advances. For example:

Think of stem cell research.
Think of intellectual property.

Think of the tension between standardization and product differentiation, a modern version of the tragedy of the commons.

What about how political borders, even international boundaries, are threatened by the Internet? Why can't we stop e-mail spam? What are the practical ways to avoid global warming?

Do these have to be settled by vested interests without serious scientific or engineering knowledge?

Examples abound where the public would be well served by new technologies, standards, or norms of behavior, but they are too disruptive for society to handle. How can the public be best served? How will civilization come to the scientific frontier?

Who has the expertise to help society adapt to new technologies? Not politicians. Not businessmen. Not attorneys. Yet these are the leaders of America. If they can't do it, who can?

You guessed it. Engineers. Here is an important new responsibility at least some with an engineering background should undertake -- helping societal institutions adapt to advances in technology. This is the form of leadership the world needs now, and one that no other profession can provide.

HANDOUT #4

So here is my vision of what engineers should do in the future. They will still be defined by their educational programs, but a new degree program leading to societal leadership (not just industrial leadership) will be needed. Note that the result will be that no longer will technology be expected to conform to society, but now society will be changed to conform to new technology.

Now let me be the first to confess that I don't know how to do this. In the past, society has relied on general education for training its leaders. Can this be combined with engineering education?

This is really important. Who will put together and teach the new programs?

Alas, not me. This is, after all, my Last Lecture.

Thank you, and adieu.