(Text of address for the Symposium for the Centennial of Electrical Engineering at the University of Notre Dame, March 26, 1996.)

Will Electrical Engineering Education Survive Another Century?

James L. Massey
Signal & Information Processing Laboratory
Swiss Federal Institute of Technology
CH-8092 Zürich

1. Introduction

I remember a cartoon strip several years ago in which Peppermint Patty, who was sitting at her schooldesk and frowning over some paper, taps Lucy on the shoulder and proudly announces "I've got it all figured out!" Lucy was naturally curious and asked "What have you figured out?". "That there are more questions than answers" was the reply. "So what?" said Lucy. "So try to be the one who asks the questions!" was the wise advice from Peppermint Patty. Unfortunately I had forgotten this bit of wisdom when Professor Dan Costello pressed me to give him a title for this lecture. I recklessly proposed the title, "Will electrical engineering education survive another century?," oblivious to the fact that it would be I who had to come up with an answer. A professor should know better. Our business is questions, not answers. The more I thought about my self-inflicted question, the more uncertain I became about what my answer should be. But Peppermint Patty was undoubtedly right. I had no trouble posing further questions such as "what is electrical engineering education?" or "what is an electrical engineer?" or even "what is an engineer?" It became apparent to me that I could not answer the first question until I had somehow answered these further questions. Other more particular questions that I could not gracefully avoid, such as "is electrical engineering an appropriate course of study within a university? or "within an avowedly Catholic university?", came quickly to mind.

Before taking on any of these questions, I would like to spend a little time reflecting on the cause of our presence here today, Notre Dame's appointment one century ago of its first Professor of Electrical Engineering. It seems to me that the answers to all my questions can be linked to those events that occurred here one hundred years ago.

2. Electrical Engineering Comes to Notre Dame

Curricula in civil engineering and mechanical engineering were established at Notre Dame during the presidency of Father Thomas Walsh, who was only 28 years old when he became the university's seventh president in 1881, a post he held until his premature death twelve year's later. Exactly when the university decided to expand its engineering curricula to include electrical engineering is not entirely clear. We do know that in the fall of 1894, Father Andrew Morrissey, the eighth president of the University of Notre Dame, and Father William Corby, who had been both the third and sixth president, made a trip together to Chicago to get the advice of the City Electrician. They were seeking his suggestion of a suitable candidate to become the first Professor of Electrical Engineering at Notre Dame. The City Electrician referred

Morrissey and Corby to a certain Dr. Hornsby, who immediately recommended Jerome J. Green for the position. Green was then keeping body and soul together by teaching night classes in electrical engineering subjects in a Chicago school--for $2.50 per night! Green was born in Somerset Ohio on December 26, 1865, and, with very little formal education, had become a high school teacher before going on to Ohio State University where he obtained his "Bachelor of Mechanical Engineering in Electrical Engineering" degree in 1893. Unable to find regular employment as an engineer during the economic depression of that time, he eventually landed a temporary position in the school that Dr. Hornsby directed. We can imagine Green's joy when Father Morrissey accepted Hornsby's advice and offered him the professorship. It turned out to be one of the best appointments that Notre Dame has ever made.

Electrical engineering began at Notre Dame when 29-year-old Professor Jerome J. Green arrived on the campus early in 1895. One of the most significant accomplishments of Green in his first years at Notre Dame was to wheedle enough money from President Morrissey, a noted miser, to purchase a large induction coil. Using this coil, Green began to conduct experiments in "wireless telegraphy" in 1895. The German physicist, Heinrich Hertz, had first demonstrated the existence of radio waves only 7 years earlier. Green made a sequence of successful experiments with electric-spark telegraphic transmission over successively longer distances. The gross inaccuracies in newspaper accounts of his work apparently persuaded Green to make a public demonstration of wireless telegraphy in 1899 with a transmission from the tower of Sacred Heart church to St. Mary's Academy, then a mile away. This successful demonstration is thought to be the first verified radio transmission in the United States. But Green's exploits were ecclipsed by those of the 27-year-old Italian physicist and inventor, Guglielmo Marconi, who succeeded only two years later (in 1901) in telegraphing a message across the Atlantic with the same electric-spark technique. Marconi received the Nobel prize in physics 8 years later.

In the same year, 1895, that Green joined the Notre Dame faculty, the German physicist, Wilhelm Röntgen, discovered a strange new kind of radiation that he called "x-rays" to emphasize their unknown nature. Six years later, the same year that Marconi made his first transatlantic radio transmission, Röntgen received the first-ever Nobel Prize in physics for this contribution. [More precisely, he shared this prize with another German physicist, Karl Ferdinand Braun, who was honored for his invention of the cathode-ray tube.] Not long after his radio experiments were concluded, Notre Dame's first Professor of Electrical Engineering was also experimenting with x-rays. He built the first x-ray machine in northern Indiana and soon South Bend physicians were sending their patients to Green to have x-ray photographs made.

For the facts of Professor Green's career at Notre Dame, I have relied on the accounts in Father Arthur Hope's book, *Notre Dame: 100 Years*, which was commissioned for the centennial of the university in 1942. My copy of this book is marked "Revised Edition" and carries a 1948 Copyright from the University Press here at Notre Dame--I do not know when the original edition was published. The title page acknowledges that it was published with the approval of the Vatican's appointed censor of books, who happened to be Father Matthew Walsh, eleventh president of the university, and with the permission of the author's religious superior, who happened to be Father Thomas Steiner, a former Dean of the College of Engineering whose name has been enshrined in the annual prize for the outstanding engineering student at Notre Dame. I trust that Steiner would have flushed out any innaccuracies in Father Hope's description of Green's technical work at Notre Dame.

I doubt that the Notre Dame department of electrical engineering was ever as close to the forefront of research, nipping on the heels of Nobel laureates, as when its first Professor of Electrical Engineering was here. Father Hope ends his comments on Green with this rather quaint sentence: "In 1914 Jerry Green went to California where, until his recent retirement, he taught in the schools of the southern part of California." I hope that someone will someday give us a fuller picture of this extraordinary man, particularly of what he did after leaving Notre Dame.

3. The Profession of Electrical Engineering

You will note that I have let myself be distracted from the questions that I intended to address, but I will dally no longer. To answer the question "what is an engineer?" requires first that we distinguish engineering from science. In principle, this distinction is quite clear. The scientist is after knowledge of how the world works; the engineer is concerned with how to put this knowledge to use. But I doubt that there has ever been a scientist who was not also something of an engineer, nor an engineer who was not also something of a scientist. Jerry Green was certainly motivated primarily by the thirst for knowledge in his radio experiments and primarily by the desire to apply knowledge in his x-ray research. It is in their emphasis on discovering or on applying the laws of nature that the scientist and the engineer differ. But I would insist that only the natural sciences come into question here. The "social engineers" whom Republican politicians are always bashing are not engineers in my book. The central prerequisite for applying a natural science is that it be quantitative rather than merely descriptive. The necessary condition for such applications to become an engineering discipline in academia is that an industry be in place that can absorb the graduates who have elected that discipline as their course of study. Biology has recently passed into the quantitative stage of its development as a science and one sees clear signs that a biological engineering industry is rapidly beginning to form. I expect that it will not be long before departments of biological engineering begin to be established.

The answer to the question "what is an electrical engineer?" is now similarly obvious. The electrical engineer is an engineer who puts to use the laws of electricity. These laws comprise: the current and voltage laws of the German physicist, Gustav Robert Kirchhoff, who died only eight years before Jerry Green came to Notre Dame, and the beautiful equations governing the relations among electrical charge, the electric field, and the magnetic field that were published by the Scottish physicist, James Clerk Maxwell when Jerry Green was eight years old. Electrical engineers take pride in the fact that Maxwell's equations are among the most universal known in science, being valid from the cosmological scale down to the smallest subatomic scale that has yet been investigated. Maxwell had succeeded in quantifying the connections between electrical currents and magnetic fields that had first been demonstrated by his teacher, the English chemist and physicist, Michael Faraday, who in turn had built on the work of the Dane, Hans Christian Ørsted, and the Frenchman André Marie Ampère.

Faraday is often considered to be the father of electrical engineering since it was his experiments with electricity and magnetism that led to electric motors and generators and to the telegraph. Faraday, who died fourteen years after Jerry Green was born, was even more of a self-taught man than Notre Dame's first Professor of Electrical Engineering, being forced to take employment with a bookseller when he was only thirteen and being apprenticed a year later to a bookbinder with whom he remained for seven years. It is said that the dexterity he learned in this craft was put to good use in his electrical experiments.

If I had to define an electrical engineer, then it would be as one who puts to use the laws of Kirchhoff and the equations of Maxwell. But I would then be forced to conclude that most of us here today who serve on faculties of electrical engineering have long ceased to be electrical engineers! I must confess that I cannot remember the last time that I myself made use of Kirchhoff's laws or Maxwell's equations other than in casual conversations with colleagues who are less estranged from electrical engineering. I am a "coding engineer," someone who applies information theory, which is the science governing the generation, representation, transmission, and transformation of information that was formulated in 1948 by the American electrical engineer and mathematician, Claude Shannon, a native of Michigan. There is not a scintilla about electricty in Shannon's equations. Others among us are control engineers. The new professor of automatic control in the electrical engineering department of my present home institution, the ETH in Zürich, came to us from a chemical engineering department--which shows how much control engineering has to do with electricity, or with chemistry for that matter. Still others among us are systems engineers or signal-processing engineers, neither of which specialties has anything to do with electricity. And the list goes on.

The electrical engineer has become an endangered species on faculties of electrical engineering. It should come as no surprise then that electrical engineering subjects are also gradually vanishing from electrical engineering curricula. I remember during my service on the Notre Dame electrical engineering faculty being quite alarmed when we eliminated the course on Maxwell's equations from the requirements for the Bachelor of Science degree in Electrical Engineering for those students who chose the new "computer engineering option." I am enough of a traditionalist that I still fret over that decision, but I am also enough of a realist to admit that it was the right decision.

The Institute of Electrical and Electronics Engineers (IEEE) with about half a million members is the largest professional society in the world. Does this mean that electrical engineering is the most widely practiced profession? Far from it! Within the IEEE are no less that thirty-five societies, such as the Information Theory Society, the Control Society, the Signal Pocessing Society, the Communications Society and many others that have nothing, or virtually nothing, to do with Kirchhoff or Maxwell. "Real" electrical engineers have become a minority group within the electrical engineer's own professional society, the IEEE, and their percentage is steadily shrinking.

How did this come about? Why is the real electrical engineer no longer the master of his own house? Part of the reason is that God was kind to electrical engineers. Electrical quantities are the easiest ones in nature to generate, to transmit, to process, and to measure or detect. Even nuclear power plants first convert the thermal energy created from nuclear fission to electrical energy for distribution to their customers. Gas lighting is often thought to be romantic, but electrical lighting has no real competition in most situations. Virtually all of our technical communications is conducted with electromagnetic waves, whose frequencies range from a few kilohertz on up to optical frequencies. The earliest analog computers were mechanical devices like Vannevar Bush's differential analyzer, which Claude Shannon worked on and reasoned about when he was a graduate student at M.I.T., but were replaced by the much superior electrical analog computers as soon as electronics engineers had learned how to make reliable operational amplifiers. The trademark of yesterday's engineer, the slide rule, has been relegated to the dust bin by pocket-size electronic calculators that are as powerful as the room-size digital computers that I used thrity-five years ago. Electrical engineers now routinely pack millions of transistors within silicon chips whose area is the size of a thumbnail--no other technology can compete with the signal-processing or computational capability that can be achieved in this way. Charles Babbage designed a mechanical digital computer conceptually more than one hundred and fifty years ago, but no real digital computer could be built until World War II when electronic devices with two stable states could be realized.

"Possession is nine-tenths of the law" is an old legal adage, but one that applies to the engineering professions as well. Because electrical engineers were essentially the only people building communications systems, it was natural for them to be the first to ask fundamental questions about the nature of communications. When a genius like Claude Shannon did this, the result was a new science. Because electrical engineers built the first digital computers, they were among the first to think about what is fundamental in the computing process. The result was computing science, still in its developmental stage but growing by leaps and bounds. In all those application areas where the electrical engineer enjoyed a technical monopoly, such as communications, computing, signal processing and the like, electrical engineering expanded its borders to include the new scientific theories that were required to guide applications in these fields. Communications engineering, computer engineering, signal-processing engineering and other new engineering fields were quietly appropriated by electrical engineers and electrical engineering educators as their exlusive provinces. Where the electrical engineer enjoyed no monopoly, the result was different. Electrical engineers, chemical engineers, mechanical engineers and aeronautical engineers were all faced with the problem of controlling complex systems and processes and, as a result, the field of control engineering has had a more democratic development.

4. Electrical Engineering Education

You will remember that the degree awarded in 1893 to Notre Dame's first Professor of Electrical Engineering was "Bachelor of Mechanical Engineering in Electrical Engineering." I am sure that sounds much stranger today than it did a century ago. Then you were either a civil engineer or a mechanical engineer. The mechanical engineers had the greater involvement with electricity as they were the ones who built electrical motors and generators, and thus they quietly appropriated electrical engineering as a specialty within mechanical engineering. But electrical engineering was too broad a field to be kept within those confines. Whether from foresight or from serendipity, Notre Dame was among the first universities to recognize this and to treat electrical engineering as a discipline in its own right. At my present academic home, the ETH in Zürich, electrical engineering did not stand on its own legs until 1935.

Is it now time for electrical engineering to set free some of the new engineering disciplines that it has conceived and nurtured in captivity? I believe the answer is yes. I am aware that there have been many attempts to set up engineering departments along disciplinary lines rather than historical lines and that these attempts have always failed. I do not plead for such a "rationalized" structure within engineering. Rather I suggest that we should recognize the historical fact that certain fields within electrical engineering have attained the status of engineering disciplines in their own right and should no longer be fettered to electrical engineering. I salute Notre Dame for having recently split off computer engineering from electrical engineering as a wise step in this direction. The computer engineer doesn't require the same familiarity with Kirchhoff's laws and Maxwell's equations as does the electrical engineer, he has quite enough laws and equations of his own to master. Perhaps communications engineering is also ready to set out upon its own. Notre Dame enjoys a strong position in this field and could be a pioneer in recognizing it as a new engineering discipline. We need not worry about emasculating electrical engineering curricula or the profession of electrical engineering. There will be more than enough new challenges in "real" electrical engineering. Superconductivity is about to come of age and will create gargantuan new problems for electrical engineers to solve. Environmental considerations suggest that electrical propulsion of some form must replace the internal combustion engine in the coming decades. Electronics must be further developed to deal better with the optical frequency signals that have begun to dominate communication networks. Rather than weakening electrical engineering by divestiture of its non-electrical accumulation, we can create a situation where the real electrical engineer is again master in his own house and we can better assure that electrical engineering receives the substantial resources for electrical research that it will require.

Will electrical engineering education survive another century? I think not in its present form. Our own successes have made electrical engineering education too diffuse and with too little focus. In a real sense, we have lost our identity. One way or another and sooner or later, I think we will begin to see leaner departments of electrical engineering dedicated to the investigation and innovative uses of electrical phenomenon and rid of the distracting influences of the new engineering disciplines that electrical engineering has fostered in this past half-century. And I think these new disciplines will prosper on their own to an extent that is not possible while they remain under the aegis of electrical engineering.

5. Electrical Engineering within the University

One sometimes hears the assertion that engineering studies do not really belong in a university because their purpose is to prepare students for a profession. This viewpoint ignores the fact that the purpose for which universities were originally founded was to prepare students to practice the "learned professions" of theology, law and medicine. Engineering is at least as much a learned profession as these others. The engineer must know a substantial amount of science and must be able to apply this knowledge to complex problems.

I find myself very much in agreement today with what the English scientist, Lancelot Hogben, wrote in 1938: "This is not the age of pamphleteers. It is the age of the engineers. The spark-gap is mightier than the pen." [Was he thinking of the spark-gap telegraphy of Marconi and Green?] This is the age of the engineer, and what more appropriate place could there be to educate engineers than within an avowedly Catholic university. We have the biblical injunction to "be doers of the word, and not hearers only," which would be my choice for a motto to place over the entrance to Fitzpatrick Hall. We have the word of Jesus himself that the questions that will be put to us on judgement day are: did we feed the hungry?, did we give drink to the thirsty?, did we clothe the naked?, – not what did we believe? or what commandments did we transgress? To perform these "corporal works of mercy" at the scale required in the modern world is a task that only engineers, if anyone, can accomplish. Catholic doctrine in particular has always clung to the insistence that good works are necessary for salvation. It seems to me to be an inescapable conclusion that engineering education should then always enjoy an honored place within a Catholic university like Notre Dame.