INTERVIEWER: Today is July 26, 2011. I'm Larry Gallagher, and today we are in the MIT Studio speaking with Paul Penfield, as part of the MIT150 Infinite History project. Dr. Penfield was born in Detroit and grew up in Birmingham, Michigan. He attended college at Amherst, majoring in physics and working as the chief engineer on the college radio station before entering MIT in 1955 for graduate work in electrical engineering.

After receiving his doctorate in 1960, Penfield joined the MIT faculty in the Department of Electrical Engineering. From 1989 to 1999, he served as head of the electrical engineering and computer science department, overseeing the creation of the groundbreaking five-year Master of electrical engineering program, and organizing the commemoration of the famous Building 20.

For his work on the commemoration, he received the 1999 Presidential Citation from the Association of Alumni and Alumnae of MIT. Professor Penfield is a fellow of the IEEE, and former chairman of the Boston section. He received the IEEE Centennial Medal in 1984, the Circuits and Systems Society Darlington Prize paper in 1985, and the Circuits and Systems Society Golden Jubilee Award in 1999.

He is author of five books and dozens of articles in his various fields of interest, from electrodynamics of moving media to noise and thermodynamics. Dr. Penfield retired from MIT in June 2005, but still teaches a class for freshman.

Paul, thank you very much for taking the time to talk with us today.

PENFIELD: It's my pleasure to be here, Larry.

INTERVIEWER: So, Paul, your IOP profile states that you retired from MIT in 2005, yet you're still teaching six years later. Why?

PENFIELD: Because I love it. I spent my entire career at MIT. MIT is the kind of place where-- if you retire, you go off and do nothing? That's just not like us professors. Retirement, after all, at any university, especially here at MIT, is really an invention of the payroll office. That is, you don't get paid after you retire. But you can still have all the fun that you had as a professor. And I must say that my years spent here at MIT have been enormously satisfying in a variety of ways. And I've simply had fun. I didn't want to stop.

INTERVIEWER: Great. And you plan on teaching how far into the future?

PENFIELD: Only time will tell.

INTERVIEWER: During your 50-plus years at MIT, you served the Institute in a number of administrative positions. Were you able to continue to teach throughout most of that time?

PENFIELD: I did not. Some administrators-- Paul Gray, perhaps is the dominant example of someone who, while president, actually taught for our department. Other department heads have had a policy of teaching one section of a class, perhaps of a minor nature, but nevertheless keeping their hand in teaching. I discovered that I could not do that. And as a consequence, I devoted full time to administration at that time.

INTERVIEWER: And what is the subject matter, what interests you right now about the course that you're teaching?

PENFIELD: Well, the course that I'm teaching is an attempt to unify two different branches of science. My philosophy, if you like, in doing research is to try to simplify, simplify, simplify, make things easier to understand. And if I find that different branches of science use different terminology for the same concept, why not teach them once instead of twice? Why not allow one field to benefit from the knowledge gained in another field?

And in this particular case, it's information theory, which is a branch of electrical engineering. And it's thermodynamics, especially the second law of thermodynamics, which is a branch of physics and other natural sciences, and is to my way of thinking perhaps the most glorious achievement that science has ever had in its multihundred-year history. And here we have an instance in which the second law of thermodynamics, involving this concept called entropy, is extraordinarily difficult to understand. And some wits have said in the past that everybody who thinks that they understand the second law actually doesn't have a clue about what's going on. And that may very well be true.

However, people nowadays know a lot more about information and how to quantify it and how to deal with it and how to process it. And it turns out that information and entropy really are the same concept, and in suitable structures can be traded one for another just the way mass and energy could be traded one for another. So why teach them twice? Why not teach them together, and teach the differences between the two and simplify things? So that's what I'm trying to do.

INTERVIEWER: Great. And how is it that that course, that subject matter, is well suited toward MIT freshman?

PENFIELD: We developed it specifically for freshmen, and I was alarmed that our curriculum in electrical engineering and computer science no longer requires the students really to have any direct contact with the second law. The second law, as you know, is unlike conservation laws such as the conservation of energy law, which says that there's this quantity called energy which is conserved. And you can transform it, you can move it from one place to another, but at the end of the day, there's still just as much left as there was at the beginning of the day.

Entropy is unlike that, in that entropy of the natural world only increases. It can never decrease, but it generally does not stay the same. It increases. And that's a very mystifying thing. I would say that the natural scientists have never been able really to come to grips as to why that is so, and so on. And yet we humans take it as very natural that we forget things from time to time. We lose information. We never go the other way. Well, information and entropy, being the same concept-- although one's the negative of the other, actually-- so that the natural law which says that entropy increases is the same as the human law which says that the information that you know decreases. It never increases without some kind of interaction going on.

We can take entropy and move it around from one place to another. We can change its form from chemical form to informational form, if you like, in a variety of ways. And at the end of the day, it always increases. If you take a count of all the entropy everywhere in the universe. Now, these two concepts have been developed separately and independently. Claude Shannon, who really invented information theory in 1948, I believe understood that the formula for his concept of information, his quantity, was identical to the formula which was in use in statistical mechanics for entropy. However, he never believed that they were really the same thing, and I don't think it occurred to him to ask or answer the question whether one could be traded for the other in a suitable experiment.

Well, nowadays, with quantum computation going on and as electronic devices get smaller and smaller so you're controlling a larger number of bits with fewer atoms, it becomes important to track the trading of information or entropy, of one form or another, when analyzing the operation of these devices. And it's not crucial yet, but before too many years are out, it's going to be crucial with devices that you can make in standard manufacturing processes.

INTERVIEWER: Might there be an opportunity for this course to become part of the curriculum?

PENFIELD: I think the ideas from this course will become part of the curriculum. I developed the course, and Seth Lloyd has been teaching it with me. He's a professor of mechanical engineering. I developed the course because I wanted the ideas to be tested. I wanted to make sure that they worked. I think the ideas will show up in the curriculum in the future. This course itself probably will not.

But there's another ambition or dream that I have for this course. And that has to do with the fact that electrical engineers and engineers in general-- the concept of engineering and the concept of science is not well understood by our national leaders. Most national leaders are not the result of education in a place like MIT, which is focused on science and engineering and basically prepares somebody for a vocation or employment as an engineer or scientist. They're the results of a liberal arts education.

And by and large, the general education that's given to people who become our national leaders does not have very much engineering in it, and not very much science. So these people are called upon to make national decisions of earth-shaking importance, if you like, without having enough background.

A course such as the one that we developed here, being taught to freshmen, could very well form the foundation of a course which is offered to liberal arts graduates in a general university setting. It would not require heavy mathematics, would not require a lot of prerequisites, and yet they could get the essential ideas. Whatever they do with their life after that, they'd be better informed because of this.

INTERVIEWER: Okay. So it's the importance of taking an engineering-type approach to making decisions, solving some of these challenges?

PENFIELD: Well, the challenges that are faced by our national leadership basically have to do with satisfying, simultaneously, the needs of several different demands placed on them. These people have to be able to make judgments that are based on a wide breadth of information. The trouble is that most people, I would say, don't have the sense of what engineering is, or what science even is. And so they are apt to not be able to make those judgments very well.

And just a couple of courses could help, one on a conserved quantity, like energy, and one on a non-conserved quantity, like information. And those two could provide metaphors which the people could use throughout their careers in understanding what scientists are saying, understanding what non-scientists are misunderstanding about what they're learning, etc.

INTERVIEWER: So what are the challenges with introducing those kinds of courses into a liberal arts curriculum at schools throughout the country?

PENFIELD: Well, MIT does not have a liberal arts curriculum, so I'm really not much of an expert in this. I would like very much to see some universities-- Harvard is a perfect example of a university that could do something like this if they wanted to. So far they haven't seen examples of it done, and I think our course may provide an example they can look at. A course on a conserved quantity-- I'm not sure that there is an example that I know of. Probably there is, but I'm just not aware of it. I think the difficulty is that it has to be done locally by somebody in the university who passionately cares about doing it. And I'm not that person.

INTERVIEWER: Right. But from what you've outlined, there could be opportunities up the street at Harvard?

PENFIELD: There could. And if Harvard didn't want to do it, there are probably dozens of other places that could do it.

INTERVIEWER: Let's go back to the beginning. We were just talking about what you've been doing recently. I want to go back to the beginning of your education. Can you please tell me a little bit about your family and growing up in Birmingham, Michigan?

PENFIELD: Well, I was your typical geek at the time, or nerd. Those terms weren't used at the time, but they certainly seem appropriate now. At the age of 10, I was interested in making crystal sets rather than playing baseball. And I think many people at MIT share that same kind of a background. We were the consummate nerds.

INTERVIEWER: Were there others in your family, or your parents, that instilled this interest in you? Is this something that you just did on your own?

PENFIELD: Yeah, I just did it on my own.

INTERVIEWER: You were building more than your typical Heathkit. You were actually building pretty sophisticated Heathkits.

PENFIELD: Well, I did. The Heathkit, as you know, was a product line put out by the Heath Company of Benton Harbor, Michigan, right after World War II. They got all this war surplus gear, and that's how they made their living for a while. But then they realized that they were going to run out of this stuff, because the army only had bought so much that was surplus. And so they cast around for a market, and they decided to make kits where they would supply the electronic parts and complete instructions. And their success depended on having a good set of instructions which you could easily follow.

And you could make multimeters, you could make amplifiers, you could make oscilloscopes, you could make all the kinds of test equipment that was pertinent at that time. And these were all vacuum tube-type things. Transistors hadn't been invented at that time. But I made a bunch of them. I was 10, 11 years old during the war, and I was making crystal sets at that time, along with a few friends who were geeks like me.

INTERVIEWER: Was there a particular "ah ha" moment, growing up, when you realized that you had a special aptitude for doing this?

PENFIELD: I'm not sure that there was. I just always knew that I was more interested in this. And when I did playacting and that sort of thing, I playacted by setting up a radio station studio, rather than by kicking a football.

INTERVIEWER: Was there a particular teacher that inspired or motivated you to pursue this interest.

PENFIELD: I don't believe so. I don't believe so. I have no idea where it came from, but I was just interested in science. I listened to the radio and I thought radio was kind of neat. There was no television at that time, of course.

INTERVIEWER: I also read you had a keen interest in genealogy, and you can trace your family back to 1651. And Samuel Penfield was the first Penfield born in North America?

PENFIELD: Well, to the best of our understanding.

INTERVIEWER: Are you the person in your family most responsible for tracing your family's roots?

PENFIELD: No, I'm not. There are people who did that well before me. And I happen to maintain the website in which the Penfield genealogy is available online. Previously, it's been available in book form. And of course, being available online means you can make corrections and additions all the time. And I have fun doing that.

INTERVIEWER: I recall listening, I think it was just yesterday, to a keynote that you delivered at Kresge Auditorium as part of the EECS 100th Anniversary. And in it, you cited a Penfield that was responsible for some development of some early technology. Was that Penfield a descendant?

PENFIELD: That was a Penfield. He isn't my ancestor.

INTERVIEWER: Yeah, ancestor, that's what I meant. OK. It was not your ancestor.

PENFIELD: That was not one of mine. That was Allen Penfield, who owned an iron mine in Crown Point, New York. And he purchased electromagnets from Joseph Henry. And Joseph Henry was the dominant scientist in the US at that time. During the 1830s he was located in Albany, and he made electromagnets and he did scientific experiments with them. And it was very cumbersome to do such things, because there weren't batteries available at that time.

Penfield bought a couple of these things and used them to magnetize spikes on a drum which separated iron from iron ore in his iron mine. And he got increased yield because of the increased efficiency of the separation due to the magnetism. And he kept these spikes in his drum magnetized by using an electromagnet that he purchased from Henry. So that was said to be the first industrial use of electricity in the nation. And there is now a museum in Crown Point, New York. The Penfield homestead has been made into a museum which celebrates that achievement.

INTERVIEWER: So you clearly have a great interest in the history of technology.

PENFIELD: Well, it's fun. It's fun, and there are fascinating stories from history. And I think I have an appreciation that history forms a context in which you can understand the present and the vector in which you are moving toward the future. And without the knowledge of the history, you pretty much can't chart your own course.

INTERVIEWER: Certainly. Certainly. So let's talk about the evolution or the invention of the transistor, and how that impacted your life.

PENFIELD: I did not invent the transistor.

INTERVIEWER: You did not invent it. But it certainly transformed or it was a keen interest of yours, even back as a young boy.

PENFIELD: Well, I was 14 years old when it was invented in 1947 at Bell Laboratories. It was a celebrated achievement. Bell Labs had been looking for a solid state device that could replace the vacuum tube, which was notoriously inefficient in its operation. It worked very well for some purposes, but it was very inefficient in terms of power, and costly, and so on. And they were looking for something made out of solid material that could do it. And they knew that you could make rectifiers out of solid materials, the so-called point contact rectifier, the cat's-whisker, and then the galena samples that were used in crystal sets.

As a kid, 10 years old, I was making crystal sets. I knew how to do that. I knew how to wire up the telephones. I wired our home telephone so that I could have an extension in my room. And the telephone repairman came around and fixed my mistakes and left me a note and told me what I did wrong. Then a couple of years later, I used to hang out with the telephone repairmen in the congregating place in the town where I lived. And they'd teach me the techniques that they used and how they strung wire and all that sort of stuff. And I was just fascinated by that.

INTERVIEWER: I understand that you were a bit skeptical about the first generation of transistors, due to I guess their fragility?

PENFIELD: Well, I was 14 years old at the time-- 13, something like that. The transistor was announced, and I had spent time making crystal radios, and I knew how difficult it was to find the exact sensitive spot on the crystal where you could do it. And these people made a transistor by having two cat's-whiskers that were close to each other, and both of them had to be in exactly the right location, not too far apart but not too close either. And I just knew that that was too fragile to be commercially possible. Furthermore, I confidently a lot of my friends, my geeky friends who would care about something like that, that I was sure that this would not amount to anything since the devices had no filament, and everybody knows that vacuum tubes had filaments. Of course, that was the whole point.

INTERVIEWER: So how would you describe William Shockley's contributions to transistor technology?

PENFIELD: Oh, well, he was the father of all that kind of stuff. He headed up the whole group at Bell Labs that developed it in the first place. And he personally invented the junction transistor, not the point-contact transistor, which was the early one. But three years later, he came up with the theory of the junction transistor in a glorious paper in 1952. He laid it all out and made it actually believable. And Bell Labs started making some of them. Companies started making some of them. The first application of transistors that were really reliable like that-- and those were the first ones that were--

INTERVIEWER: Reliable. That was the biggie.

PENFIELD: --reliable and manufacturable. The first applications were to hearing aids. And Raytheon, here in Massachusetts, was one of the companies which wanted to get into this business. And they made transistors specifically for hearing aids. Now, most of the transistors then didn't work very well, and so they were the rejects. And so here they have maybe five or six transistors that work well that they could make hearing aids out of, and 50 or 100 transistors that didn't meet specs. What are they going to do with them? Very cleverly, they relabeled them and made them available to people who were hobbyists, who could then develop circuits of low quality, but nevertheless innovative circuits, making use of them. And they gave them away, or they sold them very cheap. You could actually buy transistors very cheap. These were rejects from the--

INTERVIEWER: Did you get access to any of those? Did you get one?

PENFIELD: Anybody could buy them. You could buy them at Allied Radio Company in New York, or Lafayette. Or Allied was in Chicago, I guess. Lafayette was in New York. You could buy transistors from there, and if you understood how a vacuum tube worked and you understood how a transistor worked, you could actually make circuits.

INTERVIEWER: So when did you start actually building things with transistors?

PENFIELD: In the early 1950s. It was fun. I had built some stuff with vacuum tubes before. I figured it would be fun to try transistors. I burned out some by soldering them too close to the body, and made all the usual mistakes that people made at that time. But I actually got some circuits to work, and I had a lot of fun doing that.

INTERVIEWER: So how did, then, you decide to go to Amherst for your undergrad education?

PENFIELD: I basically didn't think about it. I just followed advice that was given to me. My grandmother thought that I ought to go to MIT, but she didn't know anything about it. My parents thought that I should probably have a liberal arts background, and so they pushed Amherst as well as some other places. And I eventually got accepted at some places, the same as happens today. And I made the choice on not very good grounds, but I think it was a good choice anyway.

INTERVIEWER: Did you go to Amherst with the intent of following-- at the time, there was a 3-2 program at MIT?

PENFIELD: Yes, I was.

INTERVIEWER: Can you talk about that a little bit?

PENFIELD: Yes. The so-called 3-2 program, which existed at that time, was between MIT-- other technical universities might have done it also, I'm not sure, but certainly MIT did, in concert with half a dozen or more of the small liberal arts colleges. And the idea is that you can go three years to the liberal arts college, then come to MIT, go two years, and get two Bachelor's degrees at the end of the five years, one from your first institution and the second one from MIT. Amherst had that arrangement with MIT. Williams did. A variety of other schools did as well.

And I thought it was a wonderful idea. However, by the time the three years were up, I thought, I'm having so much fun here, I'm just going to make it a 4-1 instead of a 3-2. It didn't work out quite that way. It was four, one and a half or four, two, or something like that. But it didn't matter, because I got into MIT. The reason I got in was that I had been intending to come as a 3-2 person, so I was not unknown to MIT. And that, I think, helped my admission.

After I got here, I had to enroll as an undergraduate because I lacked the engineering background. I found it relatively easy, because my physics background and my math were fine. I got those at Amherst, so I was able to go fairly rapidly through the undergraduate requirements. When I did that, and I satisfied all the degree requirements, the said, oh, you don't need a degree. Why don't you join the doctoral program? So I did. The rest is history.

INTERVIEWER: That sounds like such an intriguing program, and one that would probably be popular today. But I have to think that if somebody were to spend three years at a liberal arts college-- if that program existed today, and they were to spend three years somewhere else and come here for two, it would seem, knowing what I know about the current undergraduate curriculum, that it would be difficult for those 3-2 students to get the same level of technical education that a four-year MIT undergraduate would get.

PENFIELD: I don't think so. I don't think so. They can pick up the mathematics and the basic sciences which are taught at many different small undergraduate colleges. Wellesley is an example of a college which could do this very naturally. They teach science very well, perhaps not engineering. And then they come to MIT. I don't see any reason why it couldn't work today.

INTERVIEWER: What became of the 3-2 program?

PENFIELD: It was abandoned. I don't think it was too popular. If it had been popular, they would have figured out ways to make it continue, I'm sure. But I don't personally know. I lost sight of it.

INTERVIEWER: So, going back to Amherst, how did your involvement in the college radio station add to your education?

PENFIELD: We did a lot of activities, of course. And I joined the radio station because I was interested in audio and in electronics and circuits and all that kind of stuff. And I was the only geek there, so I had full reign to do whatever I wanted to and nobody could argue with me. If I wanted to change the microphones around, I could do that, and they would just go along with it. And that worked out well. It gave me some practical experience. Then it also gave me an interesting project that turned into my first publication, as it turned out.

One of the things that we wanted to do from time to time was a remote pickup. And a remote pickup-- if you're going to a different city, you call the telephone company and say, I want a radio loop between here and there. And Larry, you probably know what a radio loop is. You attach your little remote amplifier at the far end, and you have a direct loop back to the station and they can put you on the air from wherever you are. We did remote sports broadcasts that way.

We wanted to do something similar when there were events on campus, either lectures or concerts or recitals or sometimes just plain incidents that happened, bonfires and rallies and that sort of thing. We wanted people to be able to walk around and make broadcasts. Previously, what we had done is take along a tape recorder, which at the time were rather large and you had to strap it onto your back to carry it around, unlike today's tape recorders. And then you had a microphone and the reporter, the talent, would talk into the microphone. And then you'd run back to the station and play it. It wasn't done in real time. And we wanted to do it in real time.

One of the things that we did was wire up the campus. We climbed through all the steam tunnels. We hacked into the lock systems. We made our own keys just the way MIT people did at that time, so that we could get into all the buildings and not have to call the campus patrol to let us in. And we ran wires from our building to all the other buildings on campus. Then I decided what we needed was a portable remote amplifier. And the purpose of a remote amplifier is to amplify a microphone signal up to a few volts to transmit back to the station. If you try to transmit the microphonic signal directly to the station over a set of wires, there's too much noise. It doesn't work. You have to amplify it first. That's true today as well as it was 50 years ago.

Well, 50 years ago, the only way of doing that was vacuum tubes. But hey, the transistor had just been invented. And this was the early 1950s and Raytheon was making these transistors, the CK721 and the CK727, the CK722, depending on whether they were low-noise or regular-noise or more rugged, and so forth. They had this line of rejects from their production of hearing aid transistors. And they were relatively cheap. So I designed this little remote amplifier. And it was nice. The only thing is there weren't any power transistors at the time. So the only thing I could do is do the preamplification-- I had to follow that by a tube which could put out enough power. So you have to have the battery to run the tube and a little tiny battery to run the four transistors that were in there.

Well, I could see where this was going, but I decided to build it with what I could do at the time. And in the summer of-- I think it was 1953, I was at home and I just built up this little remote amplifier. As I recall, it had two microphone inputs, so the interviewer and the interviewee could each have their own microphones. And then in the fall of 1953, I brought back to Amherst to the radio station.

And the engineer would strap it on his back. And it was fairly lightweight. It could be done. We'd run a pair of wires down to the nearest the point, using alligator clips to clip onto the radio loops that we'd put all over campus. And he could do a real-time broadcast from anywhere on campus that we could run a pair of wires. And that was an innovation. It hadn't been done before.

INTERVIEWER: Well, yes, it was one of the first applications of transistor technology for audio transmission, wasn't it?

PENFIELD: I believe it was. There were obviously a lot of companies that were working on this, trying to do it. And the company having to do it, of course, had to make something which was rugged, was much more reliable, and was able to be sold at a profit, and so on.

INTERVIEWER: But meanwhile, as an undergraduate student at Amherst College who's building this, and you're doing it at the same time companies are developing this?

PENFIELD: That's right.

INTERVIEWER: You're originating these remote broadcasts in Amherst with stuff that you put together yourselves?

PENFIELD: That's right. That's right. It's something that I put together myself. And I didn't have to have the quality of robustness that a commercial product would have to have. So I was able to do it without, necessarily, the intense engineering which should have been done at that time.

INTERVIEWER: Did others in the Amherst student body-- were they aware that there was this kind of cutting-edge application of this technology going on on campus? Or did they just accept it?

PENFIELD: No, they said, "oh, that's neat. Now we can talk and not have the delay getting the tape back." So they thought it was neat. And they figured out how to make use of it in their broadcasts. And we had a student riot at one time, as happens at many colleges of course. And I forget what the incident was. But here's the engineer out there in the middle of it, trying to make sure that the wire which led back to the nearest building didn't get trampled on, and the announcer interviewing people right on the spot. And it was going on over the air as he was doing the interview. This was something that I don't think had been done before at Amherst. It was a lot of fun.

INTERVIEWER: And there was an article written about it. Did you write the article? Or was somebody else documenting that this took place?

PENFIELD: I wrote the article. I decided that this was an interesting application. I hadn't seen any article about this, and I didn't know anyone who'd done it. So I wrote it up and I sent it in to *Audio Engineering Magazine.* Next thing I knew, they published it. And I was surprised. And they shortly thereafter sent me a check. They paid $28 a page. Or was it $30? I'm not sure. And this occupied about three pages, and so I got a certain amount of money from this. And at that time, that was very welcome.

INTERVIEWER: So then that led to-- because I know that you went on to write quite a bit in graduate school, which we're going to talk about, but what I want to do is to get you to MIT. So how did you decide-- did you know already that you were going to be going to MIT after Amherst? Did you know before you went to Amherst that that was the next step?

PENFIELD: Oh, yeah. I also applied to the University of Michigan because I thought they had, and I know that they have, a good engineering school. And they still do. I would have been happy at the University of Michigan also, I think. But MIT was closer to Amherst. University of Michigan was closer to home. MIT accepted me and so I went.

INTERVIEWER: So let's do go to, then, your prolific writing career while a graduate student at MIT. Tell me about how all that developed.

PENFIELD: I don't know that it was prolific at all. But I did, after successfully writing this article and getting paid for it, I thought, this is pretty neat. Maybe I can do some other things. And I had some other ideas for projects that I could do. While I was still at Amherst, I developed beach phonograph amplifier. And the way that worked is that there were these windup turntables for 78 RPM records. And the windup turntable used to have an acoustic arm, and then the acoustic arm would play it. And there would be no electronics.

So I substituted for that a regular crystal which was used in other audio gear at the time, but still the windup motor, and then later a transistor amplifier and speaker and that was neat. It worked. And I took a photograph of a couple of my friends on the beach with it. And not only was the article published but they used the picture on the cover of the magazine. So I got a little extra money for that.

Then I did other projects. I made a headlight dimmer for automobiles, which is based on a kind of optics with an astigmatic lens, and a transistor so that you could see lights coming on the horizon but not coming too high or too low. And so it differentiated between streetlights and oncoming traffic, and it would automatically dim your lights when a car was coming. It worked, but I'm not sure it was practical. I wrote it up and published it, and got paid for it also.

I made some other things, a guitar amplifier and various-- there were a lot of projects. During a certain period of time from 1954 up until I got my doctorate, I wrote several articles about transistors, some of them about construction projects which I had done. I loved to do the construction projects, design them and carry them out and photograph them and document them and sell the articles. And some of them were how-to articles about care of transistors. Some of them were the theory behind transistors.

It turns out that transistors had just come into the public view. Not many people who were hobbyists in electronics knew about transistors. And I did because I studied them. It was a fortunate coincidence that I was the right person at the right time, if you like. And I knew that. So I would sit down while I was a graduate student at MIT-- as an undergraduate and graduate student, as I explained. I had one and a half years as an undergraduate.

During that five-year period that I was at MIT before I got my doctorate degree, I actually sat down in the evenings and on weekends and I'd grind out one article after another after another. And I could do them fairly prolifically.

INTERVIEWER: Well, that's why I used the word. Because you did. You had quite a bit of-- in fact, I read where the income from some of this writing actually one semester paid your tuition.

PENFIELD: Oh, yeah. Tuition wasn't very much then. It was only $500 a semester. But rather than have an assistantship, I figured I could make more money writing. And I think maybe I did. My wife had a job, so I didn't need to worry about eating. And I simply wrote one article after another after another and made enough to pay the tuition. I joke and say that I put myself through graduate school writing articles. Now that's a stretch, to be sure, but it actually happened one semester.

INTERVIEWER: So tell me about your first impressions of MIT, particularly compared to your experiences at Amherst.

PENFIELD: My first impressions of MIT were that this was a really geeky place. At Amherst, I'd been the only geek in town, in a certain manner of speaking. But here, everywhere I went, there was another one like me. And it was great to see these people.

INTERVIEWER: You felt you belonged, right from the get-go.

PENFIELD: Yeah. Well, I felt I belonged at Amherst, also. I never had a sense of not belonging. But I knew I was different from most of the people there, who have gone on to very fine and illustrious careers, but they weren't interested in engineering. And I was.

INTERVIEWER: So you must have had so many great relationships with faculty as a graduate student, given the fact that you were so eager to test things, try new things, roll up your sleeves, build things. What what was the graduate years like?

PENFIELD: Well, it was a lot of fun being a graduate student here. I guess three or three and a half of those years I was actually a graduate student. In the first year and a half I was still doing undergraduate. So as an undergraduate I had great fun understanding how the physics that I had learned actually applied. You could do quantitative things with it. You could actually solve for field configurations. I knew that fields existed, but I haven't known how to actually calculate them in any sense. I didn't have any judgment about what they were. This is the difference between science and engineering. And I picked that up. That was fun.

Then, watching the engineering faculty and the fun that they had--

INTERVIEWER: What were some of the more interesting faculty that you worked with?

PENFIELD: Well, I didn't work with Doc Edgerton, but of course everybody knew him. And he was a lot of fun. We had annual Steak Frys in Course 6. And he would come down with his guitar and play. And I used to play guitar, and he was much better than I was, but he invited me up anyway, and we made fools of ourselves. And we had a lot of fun.

I worked with Hermann Haus on my thesis. And the way that that turned out is that I was in charge of the rotating machine lab one year. Rotating machines were on the way out as far as the education here goes. And I sort of knew that. Westinghouse had made what was called the generalized machine, and they had modeled certain parts of it, but we didn't have a model which was inclusive. And I suddenly realized that this was true, and I looked around, and I didn't see anyone else doing it. So I went home one night and developed the general model, all the equations necessary for the general model. It was too complicated to use for very much, but there it was. And I made it available to all the others.

I was put in charge of that, and then I was also interested in the IEEE, the Institute-- well, it was the Institute of Radio Engineers at that time. They put on a series of lectures by eminent people. And one of the people gave a talk about masers, which had just come out. These were the predecessors to lasers, which are so common today, but at a lower frequency. And they mentioned some conservation laws that had been developed for masers. They were known as the so-called Manley-Rowe equations. And I looked at them and I figured, gee, they also ought to apply to rotating machines, not just to the kind of devices that were used that these physicists.

And so I figured out, well, gee, maybe I can make some of the circuits that they had made, but on a much lower frequency scale-- not for any practical purpose, but just to see whether they'd work. One day I was in charge of the laboratory using this generalized machine, and all the students were doing their stuff. And I had nothing to do, so I grabbed one of the other students, and the two of us together sat down and I explained what I wanted to do. And then he said, yeah, I think this ought to work. We sat down, took an hour, and got it to work.

That other student turned out to have an illustrious career. That was Al Oppenheim of our department, who had quite a career here at MIT and is still on the faculty. He used to say later that he wrote his first technical paper with me when the two of us wrote that up as a technical paper.

INTERVIEWER: I would imagine, given your skills at both writing and building things and experimenting, that you were on a fairly fast tenure track.

PENFIELD: I think so. I got the doctorate three and a half years after becoming a graduate student.

INTERVIEWER: And then how long after that did you become tenured faculty?

PENFIELD: I just rose through the ranks. At that time, the department was expanding, in part because the Ford Foundation was in trouble with the IRS. They had to give away a lot of their money or they were in jeopardy of losing their tax exempt status. So they gave a lot of it to MIT and established Ford postdoctoral fellowships that were available to hire new faculty. Well, I was one of those.

Many of those people were told explicitly, you have a one-year, or two-year, or three-year, as the case may be, appointment and that's it. And I heard them grumbling among themselves, and then I realized, I hadn't been told that. I was one of these also, but nobody had told me that. And I started to worry that maybe they weren't telling me something, but the fact is they weren't telling me something for a good reason. And I stayed and the others did have only temporary ones.

But I joined the faculty and rose through the ranks at the normal rate.

INTERVIEWER: So I want to talk a little bit about change. You came to MIT in 1955, over 55 years ago. I'd like to explore some of the changes and transitions you've experienced during that time. So let's start with technology. And you're talking to a fairly non-technical person here.

PENFIELD: I'm not talking to you anyway. I'm talking to the audience who's out there in Never-Never Land.

INTERVIEWER: Exactly. Exactly. But you have stated that many of the developments in your field at MIT since 1950 have to do with semiconductors in one form or another, because that technology became so pervasive and dominant.

PENFIELD: That is true.

INTERVIEWER: First as transistors, then as integrated circuits, then as VLSI, and now as system integration. Can you talk about the impact of these developments, and in particular, the practical applications of these technologies?

PENFIELD: Well, I think the practical applications of these technologies has been to take over all the electronics and the information handling. And I think it's pretty well-known and pretty well-accepted that all of the stuff that you buy nowadays, the electronic gear that you buy, is all based on transistors. And there are more transistors in a car today than were ever manufactured before 1960, every single car. Airplanes nowadays are nothing more than crates that carry around 50 million lines of code on computers that run them. Everything that's made today relies on transistors, and on semiconductors.

And the way in which that happened, though, did involve a transition between what is now known as analog electronics and digital electronics. And this actually took place-- there were the precursors of this in the late 1950s, even. There were some precursors to this. But it happened in earnest after the development of the integrated circuit in 1960, where you could stuff more and more transistors on a very reliable surface and have them permanently connected together, and not have to worry about wiring them up and soldering them and all this kind of stuff.

And the digital abstraction and the encoding of normal information into digital form really took off during the 1960s. And it became a dominant new form for electronic engineers, who up to that time had not had to worry about computers. They'd never seen a computer of course by that time. And they didn't know anything about it. But suddenly they're confronted with having to work with digital signals rather than what are now known as analog signals. And they had to relearn a lot of what they know.

So that transition which happened in electronics actually was very significant to our department, because that helped inform a lot of the developments that went on in the our department at that period of time.

INTERVIEWER: So you came here as a 22-year-old student. What aspects of the MIT culture and the MIT student body have remained constant during that time? And what are the most significant changes that you have witnessed during that time?

PENFIELD: Well, certainly the fact that MIT appeals to geeks was true then, although the word wasn't used at that time, and it's true today, and I suppose it will be true into the future, no question about it. What you're a geek about has changed. One thing that has changed I feel is an unfortunate development, that it's not possible for people with my kind of experience, my kind of hacking experience, to come here anymore.

Now let me explain what I mean by that. When I was 10 years old, I was making crystal sets, as my fellow geeks all over the country were at that time. In what is now called middle school, I learned about the transistor and I started making transistor circuits as audio amplifiers and so on. And we've gone through some of that. Nowadays, there's no challenge to that. People can make crystal radios but it's just not the same. You don't have the same thrill.

When I was young, I took apart an automobile engine. I learned how to use hand tools in doing that, and I really screwed it up and lost the car, but I only lost $75 so it didn't matter all that much. Nowadays, if you look underneath the hood of your car, you'll understand why nobody can ever service their own car anymore. It's just now all specialized. And if you take apart any electronic gear, you'll find that it's all encased integrated circuits. You can't really do the kind of things which give you a hands-on experience, at least in most domains.

Nowadays, the hands-on experience that students have when they come in is more of a keyboard. And so it's one step removed from reality. And that's unfortunate, because if you're going to teach people concepts as we want to at MIT, the best way of doing it is to have them have concrete examples of that. And then you teach the abstractions which tie together all the various concrete examples that you had. And then you can remember the abstractions and work with them in the future.

INTERVIEWER: But you've just pointed out though-- but where are the opportunities to do that? Do we have to manufacture them?

PENFIELD: I don't know the answer to this. Some of it can be deliberate kits that you can still buy today, kits from which you can make audio amplifiers or individual transistors or even cat's-whisker-based crystal sets. You can buy those. It's just not the dominant way, and people don't get a thrill out of it as much as they did. I don't know the answer to that. It might be in a higher level of abstraction before we even get here. It might be in the biological areas rather than in the electrical areas. I just don't know how that's going to develop.

INTERVIEWER: Paul, you have served MIT in a number of administrative positions. You were associate EECS department head from 1974 to 1978. You were director of the Microsystems Research Center from 1985 to 1989, and EECS department head from 1989 through 1999. What attracted you to these positions?

PENFIELD: Well, being associate department head, I had the ability and the option of finding out more of what was going on. I always had a natural curiosity about what various people in the department were doing. And so I'd quiz them on, hey, what are you up to, and that sort of thing. I thought that as associate department head-- and Bill Davenport was the department head who asked me to be the associate-- I would have the ability to get to know even more of what was going on.

I've always had the idea that you should have as much breadth as possible in your technical knowledge. You should not become too much of a specialized person. You should be more of a generalist, technologically speaking. This is in distinction to most people who get their greatest success by being more and more specialized, knowing more and more about less and less. And I decided I wanted to know a little bit about a lot of things, and that distinguished me from some of the others.

I should say, I also knew that there was within the department-- at that time in 1974-- an issue that was of overriding importance. And that was the issue of whether we were going to stay together as one department or split into two. The two departments would have been one focused on computer science and the digital side of things, and one focus on electrical engineering or the nondigital, the continuous or analog side of things. And I felt, from knowing what I did about the development of electronics, that it would be a mistake to split, but there were perfectly rational people with arguments on the other side. And I felt that as associate department head, I could have a say and have an influence in that decision.

INTERVIEWER: Paul, going back to the theme of change, can you talk a bit about the remarkable changes that have taken place in the electrical engineering department, including adding the CS, or computer science, to the department's name.

PENFIELD: Yeah. We had always been the department that was inclusive, in the sense that we wouldn't let any specialty get away. Now, electrical engineering in general is like that. Our professional society was the IRE and the AIEE. One was power-related, one was electronics-related. The two finally realized that that was not a winning strategy, so they ultimately got together in 1962. We, as a department, had developed expertise in the digital side of things, digital electronics, during the 1960s. And that was fine. Other universities had also done that and then concluded that the best thing they should do is allow these digital people to have their own department, so they could set their own destiny and have their own developments and be unfettered by being tied to ordinary engineering.

That issue came up here at MIT because some of the people felt that there wasn't adequate leadership in the department who were able to understand the digital side of things. Lou Smullin, when he was department head, made the decision to appoint two associate department heads, one that came from the computer science side of things and one from the EE side. These two faculty are still with us on the faculty. One was Bob Fano from Computer Science, and the other is Millie Dresselhaus from Electrical Engineering.

He did that because he didn't feel capable of providing leadership over such a broad range of topics. Well, this naturally led to the question, is it ever going to be possible to provide that kind of leadership, or should we split into two departments? And there were rational arguments on both sides. The people who viewed computer science as a branch of engineering felt that they should stay together. Those who viewed it as a branch of mathematics felt that they would be better off separate. That's a simple-minded view, but not too far from the truth.

The winning argument at the time, which I was one of the people who helped make, and I was proud of my contribution to that, was that pretty soon you wouldn't be able to tell the two apart, because electronics was moving in the direction of being more and more digital. And computer science was more and more interested in finding interesting ways to implement their ideas in novel circuits. So I and several others foresaw that what would happen is that these two disciplines, if you like to think of them as two disciplines, would not grow wider and wider apart in the future, but would stay more or less parallel, each with their own specialty to be sure. But it would be like one grand discipline with two branches, rather than two separate disciplines which should go apart.

And it was very important that the department structure and hierarchy should reflect this, because otherwise it would be a costly mistake to make. If the two branches were going to go and diverge from each other, then staying together would just not be appropriate. On the other hand, if they stayed together and we were two departments-- that happened at Berkeley, for example, they were two departments-- then after awhile they would feel the urge, they would recognize that something was wrong, and they'd have to get together again, which Berkeley did to their credit. But they've always, to this day, remained more of a separate two organizations than was true at MIT.

So this debate took place in the, I believe, early '70s. What we did at that time was put in a curriculum which would favor computer science. So we did establish a curriculum-- this was in about the 1974 time frame-- that was devoted to computer science, and a curriculum in electrical engineering. And this was as far as we dared to go in a split. After that discussion, which was led by several people including Joel Moses, Mike Dertouzos, and many other department leaders, it was decided by the faculty. I'm not aware that a formal vote was taken, but there was certainly a consensus that was obtained that we should stay together as one department.

And Joel Moses, very cleverly, decided what the name of the new department should be, and then asked the question in a way in which that was the only possible choice. He was good at that sort of thing and I admire him for it. He said, should it be the Department of Electrical Engineering and Computer Science or the Department of Computer Science and Electrical Engineering. And the department actually, I believe, did vote on this, give an expression of opinion. We changed the name at that time to give more prominence to the computer science aspect. And I don't think we've ever regretted, since that time, that decision. And I feel, looking back, that that's the most important decision this department has ever taken at MIT.

And it was effected in 1974. And Bill Davenport then became department head and he asked me to be associate department head. And I felt that I could help implement this. Now, I was one of the few people who had background in both the digital and the analog side of things. So I was able to see both sides.

INTERVIEWER: And so-- but the debate presented itself again some years later. Did this whole question get reopened, where there was a faction that still wanted to split?

PENFIELD: No. The decision was made. Nobody ever brought that up again. The question was how to implement that decision in terms of curriculum and so forth. If we are going to stay together, and if we believe that the two disciplines are really one discipline why shouldn't we have similar curricula? Well, I was placed in charge of a committee to establish what became the common core curriculum in the department. And I got a lot of people that I respected a lot on it, and we developed four courses that covered-- two from computer science and two from electrical engineering-- that every undergraduate had to take, no exceptions. And then from then on, you could specialize more. That worked for many, many years.

INTERVIEWER: Then you went on to become-- and I do want to jump to when you were department head. Because that was a significant period of growth as well, particularly growth in the popularity of the major. And you had to deal with all of that as department had in terms of resources, in terms of demand. What would you say were some of the most significant challenges associated with leading that department, particularly the largest department at MIT?

PENFIELD: Well, I think the most the most important challenge that I had-- and this was true when I was associate department head. It was also true in the 1980s when I undertook the development of the VLSI program, and was my most important challenge in the 1990s when I was department head. It was to make sure that there was a good ambiance and a good feeling of trust and respect between the electrical engineering and the computer science side of things, so that nobody would ever bring up whether we should break apart for the wrong reasons. In other words, if you don't like the person in the department that you have to deal with, well, then, there's an issue and you use some pretext to break it apart. I didn't want that to happen, and I felt that people from all disciplines had to understand their counterparts.

Well, in the 1980s, when I was running the VLSI program, there was a lot of research opportunity to take people with expertise on one side or the other and make them work-- and induce them, not make them work, but induce them to have research which touched on both sides, and to supervise students from both sides. And this got them to like each other and like their abilities a lot, and to have respect. And I also did a lot of that during the 1990s when I was department head.

INTERVIEWER: The whole is much greater than the sum of its parts, in this case.

PENFIELD: Yeah. All the interesting research at a university takes place in the cracks between the boundaries, between one department and other. I wanted to make sure that there was no crack that developed between EE and CS, where a lot of interesting research should go on. And that certainly has been a major concern of the department, to be able to do that. And that goes on to this day.

INTERVIEWER: And so it sounds like that partially answers this next question, but what accomplishments are you most proud of?

PENFIELD: I would list the accomplishments that I'm most proud of-- probably the first one, my contribution to making the decision to keep the department united rather than split in two. And I've already described that.

Second, bringing back to campus research in VLSI and integrated circuits, and my role in the establishment of a fabrication facility which today serves not only integrated circuit research but also more general research into small devices and small systems. And we foresaw that in the 1980s, that having a facility like that on campus would enable research which had never been done here at MIT before, and that this was a game we had to be in. And B: I was involved in the fundraising for that. I was involved in the administration of the research, and I made sure that the research was cross-disciplinary in nature to enforce my feelings about that. That would be the second, perhaps, major--

The third major contribution, which I do feel quite good about, is the Edgerton Center. Doc Edgerton, a beloved professor and hands-on guy, died in 1990. Within six months of my being department head, I was suddenly faced with what to do with his legacy. And his legacy consists of space, it consists of a lot of goodwill, it consisted of a lot of artifacts and so forth. And it took me a couple of years, but I worked together with Kim Vandiver to establish the Edgerton Center with pretty clear guidelines. Kim was about to become the chair of the faculty at that time. And I talked to Kim at length, over and over and over again. And I could see that he really would like to see something happen that was appropriate.

And he had such good ideas about what to do with Doc's legacy, and I had the space, so I could contribute something important to that. He had that personal experience of having worked with Doc, an experience which I did not have. And furthermore, he had a good sense of what something like that could do for MIT and for the nation, in providing an opportunity that we don't otherwise have to provide hands-on experience to students who, as we discussed a few minutes ago, today arrive at MIT without having had any hands-on experience.

He hemmed and he hawed because he knew he was slated to become chair of the faculty during the early 1990s. Finally, he said he saw his way clear to serving that and then taking over the Edgerton legacy. So we established the Edgerton Center. We ran it for a long period of time within the EECS department. Finally, they got enough stability to become an independent entity, and I'm very, very pleased with how Kim has handled the Edgerton Center ever since.

And he's attracted outstanding people. Amy Smith certainly is one of them, Ed Moriarty is another. There are a whole bunch of very good people who have a mission of outreach and of providing hands-on experience to people before they come to MIT and after they come to MIT. And they certainly do a service for the community and for the nation that's just wonderful.

INTERVIEWER: So was the fourth floor of Building 4-- was that space part of the EECS space portfolio?

PENFIELD: Yes, it was.

INTERVIEWER: It was.

PENFIELD: But it no longer is, of course. Now it's the Edgerton Center. And I'm very pleased with how that has turned out. And I played some little role in the establishment of that.

INTERVIEWER: It's still very vibrant, particularly during the summer. You walk down that corridor, students from all over, young people-- that's a great legacy.

PENFIELD: Yes, it is. Another thing that I was very pleased to have been able to do during my stay as department head had to do with the development of an undergraduate curriculum. And the best way of looking at that is to ask the question, what is it that engineers are apt to do after their education.

MIT provides a vocational education. That is, this is not a general education. This is not liberal arts. We provide vocational education, and the assumption is that our graduates want a career acting as an engineer, in practice. And ever since the department was founded in 1902, that's been the dominant undergraduate mission of the department. And that was very nicely articulated by Dugald Jackson, who was one of our long-term department heads, who arrived here in 1907.

And he wrote, shortly before coming here from Wisconsin, that he respected technicians, but he knew that technicians were not same as engineers. Technicians apply technology to solve practical problems, and scientists develop science. But what engineers did was in between the two. Engineers would apply known technology to solve problems but also invent new technology as necessary, using known science. And scientists provided the science, engineers converted that when necessary to new technology or new techniques, and technicians could then apply it as well as engineers.

And this worked very well until the second World War. And in the 1940s, in the World War II, the radiation lab here at MIT proved that that didn't quite work the way Jackson intended, because in the development of practical radar-- radar was invented in England, but it was made practical here in the US in a development phase. It turned out that the people who made the outstanding contributions were scientists, not engineers. Engineers played a supporting role, an important one to be sure, but a supporting role. Scientists played the more innovative roles. And they were used to thinking outside the box more than engineers were, and developing new science.

Gordon Brown among others-- and he became department head and he was able to put this into effect-- he realized that engineers should be able to develop new science as necessary. At least some engineers-- not all, to be sure-- but some engineers should be educated so that they could provide new science, as necessary, for engineering applications. Because scientists wouldn't do it the right way. They weren't motivated by the-- that isn't to say that scientists are not competent or anything like that, but they are motivated by different things. They aren't motivated by the applications. So what became known as engineering science was the development of new understanding of physical nature and the laws of science in a form that can be used better by engineers.

INTERVIEWER: So you were instrumental in introducing that into the undergraduate curriculum?

PENFIELD: Not me. This was Gordon Brown, starting in-- and in order to do that, he had to basically supplement the BS degree, the SB degree which we were giving for practice of engineering, with a very strong doctoral program. So now we had two degrees. We have the SB degree for people who wanted to practice engineering, and we have the PhD for people who wanted to teach or do research into engineering science. And there are those two activities that engineers could do.

That worked fine for a while, until computer science came along. And electrical engineers had to know too much stuff, and we basically got overloaded, and it was either a matter of cutting down on the breadth that we taught our students, or cutting down on the depth, or some combination of the two. And we had two curricula, and that was a way of cutting down on the breadth. We tried this formula of having the common core, which I talked about a few moments ago-- two courses from EE and two from computer science-- followed by more specialty courses. And that held the difficulties for awhile.

But still, the solution to this, oddly enough, was provided not by us educators. It was provided by our students. Our graduates decided, or their employers decided, that if they were going to be successful as practicing engineers, they had to have both the breadth necessary to understand the new technologies that were coming along, especially digital technologies, and the depth necessary to understand them and apply them properly. You could not get by without either.

So what happened? Our students, after graduation, all went for Master's degrees. Well, not all, but a large number did. And their employers liked that, and the employers paid the bills.

INTERVIEWER: Where were they getting these Master's degrees?

PENFIELD: From MIT, but often from other places. Stanford had an outstanding program of providing Master's degrees of high quality in various areas. A lot of universities did. So there was a real demand for it. And in that sense, our students, by walking with their feet, showed us what we ought to do next. They said, if I'm going to be a successful electrical engineer in practice, or computer scientist, or whatever you want to call me, I have to have breadth, and I also have to have depth. And if it takes five years to do it, I'm going to do it that way. And the companies that hired them agreed.

And so, upon recognizing that, we figured, why shouldn't we make this more efficient for the students? And so several people at MIT in our department started thinking about ways of making it more efficient. And Bill Siebert was particularly instrumental in articulating the ideas. When I became department head, I decided that this was something that we could actually do. So I put together a study group and-- how are we going to actually implement this? And there were a lot of details to cover, of course, in something like this.

But we changed the philosophy of our department from having our flagship program be the Bachelor's program, which it had been, to being the Master's program. We introduced the Master of Engineering program in 1994 and made-- We actually rewrote the MIT catalog so that it comes first before the Bachelor's program. The Master's is our flagship program. The Bachelor's is still available, for those who want it, and there are a variety of good purposes that it serves. But we figured the Master's is what people need. It's been outstandingly popular, successful, most of our students want it.

At the same time, we introduced a new undergraduate program which was a combination of EE and CS, didn't specialize too much in either one but gave more breadth. That is overwhelmingly popular. Over half of our students signed up for it rather--

INTERVIEWER: As opposed to the MEng program?

PENFIELD: No, that's part of the MEng program. The MEng program requires you to have all the requirements for a Bachelor's degree, plus the MEng experience of one year. It's a five-year program, and you get both degrees at the end of that, is the typical schedule. But the undergraduate specializations that you would have are either electrical engineering-centered or computer science-centered, or the combination program with more breadth. And its outstanding success is that combination program, which well over half of our students sign up for.

INTERVIEWER: That's what I was going to say. You would imagine that there's a lot of incentive, or certainly interest, in getting the MEng degree, if it's only one more year then just a regular EECS Bachelor's degree.

PENFIELD: Yes. The advantage to the MEng degree program is that, first of all, students who are in good standing with good grades can be basically guaranteed a position. They don't have to go through a lot of hassle about application. Secondly, they can postpone to the fifth year some of their Bachelor degree requirements, if they wish, and postpone and optimize the last two years of their curriculum. And a lot of students do that.

Some students want to attend graduation with their class, and so they make sure they get the undergraduate requirements out of the way. But many do not. They have that flexibility. And it's basically more efficient and it provides more incentive to our students. It's been a very successful program which has now been maybe not completely adopted, but variations of it have begun to appear in other universities as well.

INTERVIEWER: And a lasting contribution to the electrical engineering and computer science department.

PENFIELD: Yes, and that's something I feel very proud about, having had a role to play in that during my years as department head.

INTERVIEWER: Let's just shift gears a little bit, and talk about research. Now, I know your technical interests have included solid-state microwave devices and circuits, noise and thermodynamics, electrodynamics of moving media, circuit theory, computer-aided design, APL language extensions, integrated circuit design automation, and computer-aided fabrication of integrated circuits. Now, time doesn't allow us, obviously, to go through and talk about each one of them. But if you could talk about, in more general terms, in your research and field of study, what would you consider to be the more interesting discoveries?

PENFIELD: The more interesting discoveries I think are the ones that simplify our basic understanding. Now, if you notice-- the list that you read, you obviously got it off my website, because I wrote it.

INTERVIEWER: A good place to get information.

PENFIELD: Yes. That is a wide-ranging list. You find very few faculty at major universities who jump around like that. The reason I did is that I have the philosophy, in doing research, that "have tool, will travel." What I want to do is I want to use some tools in one area, and when I get tired of that, I want to be able to take the tools and move over to another area. If I find some similarities when I get there, well, then I can go back and see what worked in one area and apply it to the other. It's a very fruitful strategy. And it's one which allowed me to be inquisitive all my life.

People who specialize and know more and more about a narrow specialty certainly can have very satisfying careers, no question about it. I think that my particular nature was that I was more curious about learning about things I didn't know anything about, like information theory recently.

The idea of unifying concepts from different areas-- I mentioned earlier the concept that entropy from thermodynamics and information from information theory and communications are the same concept, and that you can actually build devices which convert from one to another. This is neat, because if you're going to teach this to students, you only need to teach it once rather than second, or at least you teach it once, and then when they really learn the details of one area, they'll think back to when they first heard about it and say, oh, yes, that's the same as I heard back then. So there's an efficiency for the students that makes it easier to transmit the body of knowledge from one generation to another. I think these are very important concerns.

INTERVIEWER: This leads to my next question about MIT's particular approach to research, and particularly MIT's approach to interdisciplinary research. Can you talk a little bit about that?

PENFIELD: I'm probably not your best expert on that, but the interdisciplinary research that we do-- we're noted for that. RLE, being one of the first interdisciplinary, interdepartmental or however you want to term that, research labs in the country, came right out of the radiation lab. I mentioned the experience of the radiation lab earlier, in developing radar.

INTERVIEWER: Scientists and engineers?

PENFIELD: Yes. Found that scientists made contributions and engineers did not. Maybe they could have, but they didn't at the time. And RLE has been very successful in unifying, basically, physicists and electrical engineers, but now other kinds of engineering and scientific disciplines as well. Other interdisciplinary activities I think have been good. You could regard EECS, as a department, being interdisciplinary in the two branches. And in the future I think this will lead to possibly three branches, one in applied biology, informational biology especially, and the use of biological systems in making practical devices. I think there's a bright future there which we are embarking on.

INTERVIEWER: Exactly. There are EECS faculty that are currently occupying labs over in the Koch Center for Integrative Cancer Research.

PENFIELD: Yes. Yes, that's right. We're, I think, doing a good job. This is nothing that I did, but I do take a certain amount of pride in having established within, or continued within, the department the philosophy that permits something like this. And I think we'll see, maybe 20 years from now when the biological revolution has played its way, the next one on the horizon seems to be quantum engineering. I think we'll find quantum mechanics playing an important role in engineered systems that it doesn't play right now. I think we'll see that the manufacture of quantum devices, whatever they may be called upon to do, will be very important.

And I'd like to see our Department of Electrical Engineering and Computer Science lead that at MIT as I think it's capable of doing. And this will be, maybe, a fourth branch of the department.

INTERVIEWER: We talked earlier about transition. There's another transition I want to talk about. And that is a significant one at MIT that I know that you didn't have a lot to do with, but that was the opening of the Stata Center in 2005. Prior to that, in order for the Stata Center to be built, Building 20 had to be demolished, much to the chagrin of a large cadre of loyal and passionate occupants. I know that you spent some of your early years at MIT in Building 20. What was it about Building 20 that was so appealing to the folks that occupied offices and labs along its creaky corridors?

PENFIELD: The simplest way of explaining this is to say that, if you're running a lab and you need to run a wire from one room to another, you don't call the electrician. You take a screwdriver, you poke a hole in the wall, you thread the wire over, and you're done. It was a temporary building, and because it was temporary, nobody cared whether you poked a hole in the wall or not.

That's a metaphor, not only for actual wiring-- I mean, people actually did that, to poke holes in the walls and to run wires-- but it's also a metaphor for the kind of interactions that you can get in a temporary space by having in juxtaposition people working on different things, that bump into each other in the corridor, who have to deal with each other when it gets too hot or too cold to turn on the radiator, and by the way what are you doing, and so forth.

The fact is that a lot of very good science and engineering work got done in that structure simply because everybody knew that it wouldn't be around forever and you didn't have to pay a lot of attention to the structure itself. So you can pay attention to the work that you're doing and the people who are doing it, and if you get ideas from other people. And it sort of brought out the best in everybody who was in there. I had an office for several years in that space.

INTERVIEWER: Yeah. I mean I would have thought that-- during my career at MIT, I'd heard several times that Building 20 was going to be demolished. And then there would be some resistance and then another five years would pass. It seemed to have quite a certain amount of staying power.

PENFIELD: Well, it had staying power because nobody had the money necessary to replace it. And finally, it was recognized that there was a need to move back onto campus the computer science wing of our department. And this was an issue that had bothered our department for a long time. The physical separation between those folks interested in the bit-oriented side of electrical engineering and those interested in the atomic side of electrical engineering, if you want to distinguish it that way-- it's harder to form liaisons and collaborations with that physical separation.

So finally it came to the breaking point, I think. We have to move these people back on campus. The only place to move was Building 20, so regrettably, we have to tear down Building 20. We managed to get a wonderful design done by Frank Gehry and associates for the Stata Center itself.

INTERVIEWER: Going back to Building 20, you organized events commemorating Building 20. As you termed it earlier, you said that you organized a wake for Building 20, for which you received the 1999 Presidential Citation for the Association of Alumni and Alumnae at MIT. Tell me a little bit about your wake for Building 20.

PENFIELD: Basically, we knew Building 20 would be coming down. It had already been stripped in the sense that most of the offices-- people had moved out, and the laboratories-- people had taken their equipment and so forth. So there was a lot of empty rooms, but no actual demolition had yet occurred.

And it occurred to me, and to some others, that Building 20 engendered love from people in a way that most buildings would not. And people had fond memories of that. Perhaps the outstanding example was the Tech Model Railroad Club, which was based in Building 20 and which did some of the early digital engineering here at MIT. That's a wonderful example. But many people from many different departments were involved in Building 20, had offices or labs there. And it was decided that we should give those people a chance to grieve the loss of the building.

And so we actually organized it. They came around. And on the day of the event, one of the famous MIT hacks was a big replica of the property office sign that-- what'd it say?

INTERVIEWER: Deactivation sticker.

PENFIELD: Yeah, it was a deactivation sticker that you put on old furniture and old equipment. So they had a huge one which they hung from one of the windows. And that showed that the hacking community was with us, also. But there were wonderful stories told during that event. And on more than one occasion, somebody would be speaking of an incident that had happened, and I don't know how it happened but suddenly the wire came from here to there, or something like that. And then somebody would pipe up from the audience, yeah, I was involved in that. Just in the middle of sessions.

INTERVIEWER: That can be seen online in fact.

PENFIELD: Yes, yes, it can.

INTERVIEWER: It was called the Magical Incubator.

PENFIELD: Yes. That was the term that we had for it. We got a committee of alumni who had been on-- Ted Saad was on that committee. There were several people from MIT who were on the committee, who planned and organized the whole thing and did a very effective job, I think. And the people who came to it loved it, and it allowed them to get along without their beloved partner. So it really did serve the same purpose as a wake.

INTERVIEWER: And there's still-- what's nice is that in the entrance to, I think, the Dreyfus tower, there's a commemorative display for Building 20 over in the Stata Center.

PENFIELD: Yes, the MIT Museum did an excellent job of putting that together. I was very pleased. There is also a time capsule. There are two time capsules in the Stata Center. One is about Building 20, and it is in the Building 20 area the MIT Museum put together. Then there's another time capsule having to do with the computer science wing of the department.

INTERVIEWER: You also served the Institute in the mid-'90s as the chair of the ad hoc committee on Education Via Advanced Technologies, which issued its final report in July of 1995.

PENFIELD: Yes.

INTERVIEWER: What was that experience like? And in your opinion, did that report serve as a potential foundation for the OpenCourseWare initiative?

PENFIELD: Well, that was a fun experience, because the web had just, basically-- the graphical browser of the web, Netscape, had just come out. And with the graphical browser, suddenly everybody's eyes were open about what the web could do. And people were building web pages and so on. Then the question is, how can this influence our education? And so, quite naturally, I looked around and found out who was doing what. And there was interesting stuff going on already at MIT. I think Pete Donaldson was working in the--

INTERVIEWER: Languages?

PENFIELD: Yes, in the Shakespeare project. The results of work going on in mechanical engineering-- Professor Patera was doing that. There were a variety of interesting things going on. And I wanted our department to embrace this new technology if it possibly could. And so I organized a one-day retreat off-campus, and out of this came the formation of a committee to make a recommendation about what should be done. And we did, and we tried to demonstrate some of the technology.

In the meantime, other people were starting to do other things. We contributed toward that, although I'm not sure that our report alone actually triggered an event. Another committee was formed somewhat later that came up with the recommendation of the OpenCourseWare, which was an excellent example of how the web could be used to make the world a better place using sharing from MIT's body of knowledge.

And it reminds me that when Gordon Brown, in our department, decided that engineering research, engineering science, was an important activity for engineers to do, he made sure that other engineering department heads and deans and faculty across the country were aware of what we were doing and what our thinking was, to make sure that he got the best ideas from them and that they were able to accomplish something similar to what we were doing. So it was, again, an example of MIT taking a leadership role and making everybody know what we were doing, and as a result, fulfilling our role, making the world a better place through a leadership role. And it was that day's version of OpenCourseWare.

INTERVIEWER: So I had the opportunity to review the report, in preparation for this interview. Moore's law notwithstanding, I thought the following was a rather bold prediction to have been made 16 years ago, this from the Possible Long-Range Models from MIT section of the final report, after a section predicting networked personal computing in the dormitories. So this is from 16 years ago.

The next step after that one in student computing-- parentheses, this is very speculative, close parentheses-- might occur when the MIT campus is wired for cellular data communication and students have small portable computers which they can take with them all day for use as portable personal assistants. These computers would normally remain turned on in continuous wireless connection with the MIT network, and would be as unobtrusive as, say, a notebook, and therefore welcome in all settings. They would serve as telephones, pagers, web browsers, email handlers, notepads, calendars, and computers. It remains to be seen what new applications would motivate their widespread use.

Have you looked back on that report recently, and are you surprised at the degree to which the committee's predictions have come to pass?

PENFIELD: It's obvious, isn't it? Now?

INTERVIEWER: That's 16 years ago.

PENFIELD: Yes. Yes. Well, we understood what the technology was. We understood that these would probably be hand-sized things, because human physiology isn't going to change. The size of our hands isn't going to change. The size of our minds isn't going to change, or our eyes, or anything like that. So what could we pack into something that you could hold in your hand? And we just judged all these things were reasonable candidates for being included. And today's smartphones do it.

INTERVIEWER: Exactly. And the iPad, and all of these things. But this also required, though, the kind of wireless network connectivity that we didn't have then--

PENFIELD: --but we knew would come. We had smart people on that committee.

INTERVIEWER: So I'd like to shift here to talk about your thoughts regarding today's students, and the role of engineers in today's society. MIT's motto was "Mind in Hand." MIT's hands-on approach to learning has been a constant since its founding 150 years ago. I understand you have concerns that today's youngsters are not getting the hands-on experience they need, particularly in K through 12. What do you think should be done to provide these opportunities, and what role can MIT play?

PENFIELD: Well, certainly the Edgerton Center today is playing some kind of a role in that. The various kinds of competitions that you find, the robotics competitions for example, are an excellent example where people can get on and actually build something and program it to actually have it do something. That's moved from being an occupation of graduate students down to freshman, and then down to high school, and now it's in middle school across the nation. I think that's an example where we can get some hands-on experience.

On the other hand, this still is a little bit removed from nature. It's a little bit different from testing the laws of nature directly. You're operating at a keyboard most of the time, doing programming most of the time. Sometimes you have to deal with gears and motors and things of that nature. Whether we can devise other kinds of competitions that will excite people in middle school and high school, I don't know. That's certainly one way of doing it.

INTERVIEWER: Are there opportunities with the internet to deliver to the classroom the kinds of experiences we'd like students to have before they come to MIT?

PENFIELD: I don't know. It's entirely possible that the remote laboratory set up that Jesus del Alamo, Professor del Alamo in our department, has been doing could play a role of this sort. He has been focusing his efforts, I believe, more on providing services to developing countries that cannot afford laboratories. Instead they do them remotely. That's different from a virtual lab in which it's simulated, because the actual experiment is being done. It's just that it's being done in another part of the world.

I think it's entirely possible that some kind of systems like that could be set up to enable middle school, even younger, students.

INTERVIEWER: Could you talk a little bit about your thoughts on the role of engineers in today's society?

PENFIELD: Well, engineering is a specialty. When your car doesn't work, you take it to the garage and you hope your car mechanic knows something about his specialty. And the car mechanic probably had a vocational education to lead to his ability to fix your car. On the other hand, if something's wrong with your body and you go to a doctor, you expect the doctor not only to have his or her specialty-- whether it's cardiology or whatever it is-- you expect not only that, but you also expect the doctor to be a thoughtful and an important member of society who understands you in more than just your body. Your car mechanic probably doesn't have to understand you more than your car, but a doctor does.

Now, think of how doctors are educated. Typically, they are graduates of liberal arts colleges or universities, generalist programs, but then specialize after graduation. Car mechanics don't do that. What should engineers do, you think. Right now, I submit that the nation has a problem because our national leaders do not know enough science and engineering to make gut-level reactions to controversial statements. For example, if a lobbyist comes up and makes a statement about global warming to them, they are not in a position to intuitively understand that it's baloney or that it's true. They simply can't make a judgment of that sort. So they have to take other people's word for it.

The minute you have somebody in power who has to take other people's words for it, then that person and the people represented by that person-- namely the whole country-- are held hostage by the experts. And so you have to be very careful to get good experts. Wouldn't it be better if our national leaders had some scientific or engineering background, so that those decisions that had an impact, those decisions that had useful input to come from science or engineering, could be made more efficiently and more accurately that way. Currently, the education of engineers doesn't permit that, because MIT is a vocational school when you come right down to it. We're not a general university.

I do submit the our humanities requirement, our communications requirement, which I'm very proud to have played a role in implementing, do give people the skills necessary to a very great degree. But they are skills which ultimately are aimed at the role in whatever profession they go into, whether it's a chemical engineer or a metallurgist or whatever, or in our case, an electrical engineer or computer scientist.

What I think would be really wonderful is if somehow the engineering education community could find a way to contribute to the education of liberal arts graduates and make a contribution to general education, so that all liberal arts graduates would have a gut-level feeling for some kind of engineering. And then those that have the special talents needed to go on for leadership positions would have that as a background that they could rely on. I don't know any way to do this, exactly. I don't believe that MIT could do this without changing its fundamental mission.

Or could it? I just don't know. Could we collaborate with other universities and do something along this line? Could individual departments, for example my own department-- could we establish liaisons with colleges like Wellesley, for example, where some of our national leaders are being educated today? Can we make sure that Wellesley get exposure to some kind of engineering? And could we contribute to it in some way? I think those colleges that do provide leadership are stressed, and the students taking our curricula have no place to put this. They have all the usual excuses that can be made. But somehow, somebody has to find a way to introduce science and engineering in a way that is meaningful to today's circumstances to those people.

INTERVIEWER: Paul, during your introduction, I cited a number of the many awards and honors you've received. And I also mentioned the leadership positions you've held in a number of professional societies. Which of these awards and affiliations are particularly special and why?

PENFIELD: Well, one of the things that we have not touched on is my role with the Electrical Engineering Department Heads Association. There's an association for everything, as you can imagine, and there's one for electrical engineering department heads. I became involved in this shortly after becoming department head, and I figured, this is an odd group. Why would I have much in common with other ones? But I went to it, and I realized that what I got out of this was an appreciation for other universities and other colleges that had electrical engineering and related programs, and the difficulties that they were having, and how they related to the difficulties that we were having.

In all too many cases, what I discovered was that there were, at all too many universities, organizations that were dysfunctional for some reason or another, or hostilities within departments. And it was very depressing, often, talking to my colleagues from other-- I ultimately became president of this organization, served a year in that term, so I got to know a lot of my colleagues from other universities. And I learned that many of their problems-- they had much greater problems than I did. And I was so glad to be at a university that has a combination of high stature and public regard, has adequate resources to do things that they want, and has an understanding upper-level administration which has supported my efforts all the way that they possibly could.

When I talked to some of my colleagues at other universities, I discovered that we were blessed by having a single Department of Electrical Engineering and Computer Science. When we put it to a straw vote at one time whether they would like such a thing, all of them basically wanted to merge with their other departments, but they couldn't do it because there were too many personalities involved. At MIT, the personality issue, in our department anyway, is not a major thing. We all get along very well together in our department. And certainly among the various boards and committees that I've worked on, we also have a great degree of collegiality, and a great willingness to cooperate with others.

I would commend Jay Keyser for running his series of faculty dinners which encourages such collegiality from one department to another. I would certainly commend the various deans I've worked with. I don't know how many dean's I actually served under, but all of them had a degree of collegiality within the governance of the School of Engineering, which was very, very helpful. And certainly our focus within the department on undergraduate education as our primary mission served to unify the department in a way that, I think, is rare at MIT and elsewhere. So I really feel privileged to have spent a career in such an environment.