Oral History of Dr. Edward B. Eichelberger

Interviewed by:
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Edward B. Eichelberger: Good morning, Sumit.

Sumit DasGupta: Good morning, Ed. This interview, by the way, is going to be part of the Computer History Museum archives. And it will be used by people who are interested in the industry, as well as, potentially, for future research. So I think this is a wonderful idea that they have started.

Eichelberger: Well, let me say thank you for initiating this. We had a wonderful time many years ago working together on these projects. And I think we made a big difference, not just in IBM, but in the industry. And I think all the work that you and I did, and the rest of our team, deserves to be there, and I appreciate you doing it.

DasGupta: Oh, thank you. So in fact, it's an incredible coincidence that we are participating in this recording today. I have known you for exactly forty years because it was in 1974 when I joined your team-- in February. And I can still recall many of the anecdotes that you have related from your personal life and from the experiences at IBM. So would you please share some of your childhood memories, such as where you were born and raised, what sort of education and training you received that shaped the man and the scientist that you became later on? So with that, I'm going to turn the mike over to you.

Eichelberger: Well, thank you. We are here not too far from where I grew up in Norfolk, Virginia. And my family -- mother and dad and my brother and my sister, who are older -- we grew up on a little street called Major Avenue, which was a nice, working-class neighborhood. And we had three other neighborhoods nearby that had all my friends and people I went to school with in elementary school and went on to high school with. It was a wonderful place to grow up and live, and I wouldn't change a thing. And I had great parents.

When I was young, I was not always doing what I should have been doing, and I always found out about it very quickly. And that was that. But pretty much, they let me do what I wanted to. We had chores to do, and there was never any argument or discussion about those. You did them. And after a while, you learned to like them. I had, like I said, a ton of friends, and we went all the way through school together. We didn't have a lot of money, but there was never anything I needed that we didn't have. So it was a storybook type of growing up.

DasGupta: In fact, you had the usual chores, like you mentioned, that you had a paper route also.

Eichelberger: Oh, yeah. That was a nice thing about being in a working class neighborhood because you could get a job and feel good about it because it was needed. One of the things we had was a little, beat up, old 12-foot wooden rowboat. We were about a half a block from the water there in Norfolk, and when I turned about 11 or 12, I could use the boat all I wanted. And once a year, you had to spend a week or two scraping it down and painting it, getting it good for another year. And I loved to fish and crab out of that little boat, and it was my favorite recreation. And when you would bring home some blue claw soft-shell crabs and they would cook them up for dinner, you'd feel that you had done something. In addition to having a lot of fun, you put food on the table. So that was one of the good things about growing up.

DasGupta: And in fact, you talked about all your friends in the neighborhood, and one friend who happened to be next door was Pat.

Eichelberger: Yes, yes. One morning when I was about 12 years old, I looked out the window and across a couple of vacant lots, there was a new tenant in the house there, and there was a young lady out working in the yard. And I immediately decided she was probably the prettiest young lady in the neighborhood. And let's see, that was when I was about 12. So about 10 years later, when I graduated, the young lady and I down the street got married. And we dated for about six years before that.

DasGupta: So as a student, I know you were quite an athlete-- classic scholar athlete. So what were the sports you were most involved in?

Eichelberger: Well, like the man says, I never met a sport I didn't like, and we did everything and played everything that was imaginable. And we had our own little group that I went through elementary school and high school -- it was our little athletic club, and we had teams for everything. But the sport I was most successful at was a sport that did not exist when I went to my first year in junior high school, and that was the sport of wrestling. And we had a gym teacher by the name of Billy Martin who had been a wrestler and had wrestled in the national tournaments and done very well when he was in college. He went to Michigan State. And he decided he wanted to start wrestling in the state of Virginia, which he did.

And I managed to be on the team for four years. And in those four years, the first thing Martin did was invite the team from New York from Mepham High School. The coach was named Sprig Gardner. And they had been undefeated for about three years. And they probably had the best high school team in the country. And he talked them into coming all the way down to Norfolk, Virginia, and holding a clinic for us. A year later, we went all the way up to New York and had another clinic and wrestled them. And so that's the way you got things started. And I wrestled in four high school tournaments, and I went to four national AAU tournaments with Martin taking me around.

And the first one I wrestled in was when I was a little sophomore. I weighed about 120 pounds. It was at Hofstra College in New York City, and they had the national AAU tournament. And the first person I had to wrestle turned out to be two-time national champ that had just a week before won the national collegiate championship. He was my first competition. And so I asked Coach Martin, "Who am I wrestling?" And he said, "Well, some kid from out west." So that's the way he ran the show. And it turned out I got beat thoroughly by him, but I went on to -- and I ended up with the fourth place medal. And the coach from Lehigh University was there, and I'm sure that that exposure as a sophomore got me a scholarship three years later to Lehigh. So that was what Billy Martin did for me.

DasGupta: Which leads me to my next question. I remember you mentioning attending Lehigh. And so you got an athletic scholarship to attend Lehigh and wrestled as well as play soccer too, right?

Eichelberger: Actually, they didn't have too many athletic scholarships at Lehigh, but they had a scholarship where they were trying to get people from states other than Pennsylvania and New York, and it was called a competitive regional scholarship. But they were using it to get people that were wrestlers. That was their one big sport at Lehigh. So it was an athletic scholarship, yes.

DasGupta: OK, all right. Good. You know, as we were getting prepared for this interview, I Googled your name. And one of the hits that came up was that you are in the National Wrestling Hall of Fame. So what memories and experiences do you have that you can share from being inducted into this esteemed institution?

Eichelberger: Well, thank you. It was a great honor, and it was especially -- it happened about four years ago. And it was very, very great. They treated us royally, and one of the nice things about it, that was the hundredth year that Lehigh had a wrestling team and competed. So we were celebrating 100 years of wrestling at Lehigh, as well as my being inducted in the Hall of Fame. And of course, my high school coach and my college coach, who was named Gerry Leeman, were both inducted into the hall-- had been inducted in the Hall of Fame before that. So it was quite a fine occasion.

DasGupta: Now I assume you attended that in some place in Oklahoma?

Eichelberger: Yeah. That was at Stillwater, Oklahoma, where they have the National Wrestling Hall of Fame. But they have another branch of it now, actually, in Iowa. So the history of wrestling is half in Oklahoma and half in Iowa with the rest of the country trying to compete with them. And as a matter of fact, interestingly enough, I got beaten as a sophomore in the finals in the national by a gentleman by the name of Myron Roderick, and he beat me again trying out for the Olympic team two years later. And the next year, Myron Roderick was the head coach for Oklahoma A&M, and he turned out to be the most successful wrestling coach in the history of wrestling. So I had some good competition.

DasGupta: And in fact, you were a national champion in your weight class for two years, weren't you?

Eichelberger: Yeah. Junior and senior year.

DasGupta: Wow. That's amazing, indeed.

Eichelberger: That's because I stayed away from Roderick. We had met as sophomores at 137 weight class. And the next year, I went up to 147, and that same year, he went down to 130. And I knew why I went up a weight class, but I never knew why he went down a weight class.

DasGupta: All is well. So you know when you talk about wrestling, it's obviously a very demanding sport. So what life lessons did you learn from such activities that helped in your career later on at IBM?

Eichelberger: I'm sure everything you do in life makes a difference. I think that the heart of it is that you learn in sports that you become good in the practice room, not in competition. And that's the way you succeed. And that's pretty much the way life is in everything. If you work hard and take it seriously, you do well. But the other one we like to joke about was one of the things in wrestling that wasn't exactly fun was making weights. And the lower the weight class, the better chance you had.

So the more you starve yourself, the better chance you had. But starving wasn't a lot of fun. So all the people that wrestled had to starve a little bit, and we were probably the only people in the country that know what it's like to starve these days. And you somehow come away with -- you know, if you can do that, everything else is easy.

DasGupta: So what impact did your parents and extended family, like your siblings, have on your choice of athletic endeavor, university to attend, and finally, academic and professional career?

Eichelberger: Well, like I said before, growing up, I found lots of ways to get in trouble with my sidekick who lived across the street, and we played and did everything parents didn't want us to do. And we learned what to do that they liked, and we learned what to do that they didn't like. And we learned chores. But the rest of that -- my parents let me do what I wanted. And they never made any effort to tell me what sport to play, what school to go to, what courses to take. About the only recommendation my father ever had, and he said that in a backhanded way, was “make sure when you get out of college, you have a job.” That was it. That was the only advice, which was pretty good.

DasGupta: And which you did very well at, getting a job at a company like IBM, which both of us have a great deal of respect for.

Eichelberger: Yes. That was the best thing that happened.

DasGupta: So who were the mentors who guided you, and what lessons did they impart through childhood through undergraduate college, and, of course, later on in your career at IBM?

Eichelberger: Well, that's a long story. Clearly, starting out, it was my mother and my father. And my brother was almost like another father. He was seven years older. All of those people sort of shaped my happy childhood and a childhood that was OK. I had known for all that I can remember-- we just all wanted to go to college, even though my father had not gone to college and was unable to. We knew that we wanted to go on and get a career. And that was -- never told that, but we all just knew it. We were going to do it.

And at an early age, I got a paper route when I was 12 and was able to save some money. And when I finished high school, I had $1,100 in the bank. Now that's not a lot of money today, but that was almost two years of tuition at Lehigh, which I didn't use for that, but used for the other stuff. So clearly, my parents were number one. And as I mentioned before, my high school wrestling coach, Billy Martin, got me into college. That's pretty nice. And I had a good time along the way. And I had an equally good coach, Gerry Leeman that took me from being a good high school wrestler to a national champ. And Gerry Leeman was a national champ and also Olympic silver medalist. So, I wrestled for two of the best coaches in the country, and they both were also inducted in the Hall of Fame prior to my going there.

DasGupta: How about at IBM? In your early career, can you name a few?

Eichelberger: I would say, rather than like a mentor, I just remember the people I worked with and the people that I worked for. In particular, my first -- there were many of them, but I kind of like to remember the first boss I had. His name was Marty Kelly. And he just had a small group of guys working on magnetic devices for computers. This was 1956, and nobody knew anything about computers in those days. And he was a wonderful manager and he didn't interfere with anything I did. Told me the area that I could work in, and he was able to take the results of not just what I did but what these other 10 or 12 guys did and made sure they were used as much as possible.

And after three years at IBM, I had done some work on what we called the magnetic core shift register, and it turned out to be a major part of the data flow of the next generation computer, which was called the 7070 that they were getting started on. And we had a competition with Poughkeepsie, as we always do, in who's got the best design. And mainly because of the circuits I designed in this magnetic core shift register -- we used 4 transistors where they were using 16, and that was where the major cost of the computer was. So Endicott got the job, and everybody was happy.

And about that time -- we'll probably talk about this later -- they decided to have the first chance of sending people back to school to study for a PhD. It turned out that the head of the company, Thomas J. Watson, Jr. had decided that he wanted to hire a whole bunch of PhDs because he felt that was what we needed to enter this world of computers. And he asked his management team to go out and hire a bunch, and they came back to him and said, "Well, there are not that many PhDs in electrical engineering being generated."

And they decided to send some young IBMers back to work on a PhD. And it turned out that about June, nothing had happened. And Watson says, "Who are the people going back this Fall?" And they said, "Sir, we don't know yet." And the story was he told his management team to just go through management and select some people, and we'll send them back to school. And, of course, Marty Kelly selected me. That's how I got selected to be in the first group of people sent back on the PhD program called the Resident Study Program.

DasGupta: In fact-- you were talking about competition between Endicott and Poughkeepsie. At that time, IBM was sort of like the leading company in computers, and they would essentially generate competition within to get the best ideas out. And so that must have been a phenomenal time because when you talk about what you did, you went all the way from magnetics to vacuum tubes to transistors to LSI. So you span the entire scope of everything that IBM did.

Eichelberger: Yes. When I got there, of course, we were using vacuum tubes, and they were working on the machine that Endicott had shipped-- was called the IBM 650. And it was a very popular, small computer, and they shipped a lot of them. And so they were ready to ship the next generation. They called it the improved 650. And it was up and running and ready to be shipped or announced. Tom Watson, once again, as a brilliant leader and thinking ahead, realized that the future was not in vacuum tubes but in transistors.

And so just before we announced this machine that was ready to go out from Endicott he came out and said, "No more vacuum tube computers. They've got to be all transistors." And there we were working on solid state stuff in the advanced technology area, and suddenly it was now important because that could be part of the next machine. So that decision by Watson took something I would do that would probably be a relic and made it part of the next generation machine because we were there at the right time and our leader made a good decision, we thought.

DasGupta: And this is Tom Watson, Junior, you're talking about.

Eichelberger: That was Tom Watson, Junior, right.

DasGupta: OK. So the next question actually leads in to what you were talking about before, that you were in the first batch of employees that was sent back to campus on the newly minted IBM Resident Study Fellowship, which was a phenomenal program. And in fact, I think it was probably the first one in the country at that time for a PhD. So you mentioned Marty Kelly and, of course, Tom Watson in between at the top. Who were the other IBM visionaries who conceived of this program and really got it kicked off?

Eichelberger: As far as we knew, it was a one man show. Watson just decided he wanted PhDs, and that was it. And then when nothing had happened, he said "Pick some people and send them back to school," and that's where I fitted in because I'd finished my job and it had been successful, so I had a little bit of success and at the right level -- been out of school for three years, so I got picked because of my work. And it turned out I hadn't heard anything about it. I was looking around for what to do next.

My boss came in and -- it was middle of June -- he said, "Eddie, come with me. We need to go see the lab manager." I'd never seen the lab manager before. We walked in, and the lab manager's name was Jim Troy – he shook hands with me and explained the new PhD program and that I'd been one that had been selected to go back this year. I said, "How does it work?" And he said, "Well, it's a job assignment." That was a little different -- only one around like that. "We'll pay expenses, and it's up to you to get in school and graduate." I said, "How soon do you want an answer?" And he said, "Five minutes." And I said OK. That's how quickly that went down. And I went back to school.

DasGupta: Yeah. In fact, I remember you mentioning that you had a very short runway -- you said June, and semester started in September. So you joined Princeton. So would you elaborate this for the record? What did it take for you between June and September to find yourself in Princeton?

Eichelberger: Well, first of all, the first couple of schools I investigated -- called admissions and talked to them, and the first thing they told you is that you can't get in this year. You'll have to wait until next year because we've already closed the admissions for this year. And I did that once or twice at a couple of schools I was just looking at. But mainly, what I did was I spent 24 hours thinking about it. I figured that's all the time I had. And I immediately realized that the adviser in graduate school was the most important thing because he was the one you were there to learn from, and he was going to be your boss for three years.

And so I started focusing on people that had a reputation. And Professor Ed McCluskey had been a PhD graduate from MIT about three or four years before and was at Bell Labs and had just taken on the job of professor at Princeton. And he had written his doctorate dissertation -- a wonderful work about how to do two-level logic minimization. It was called “The Quine-McCluskey Method,” and everybody knew about it, and everybody used it, and they still do. And so he was the top of my list. And there was work done at Illinois and University of Pennsylvania, so I went to those three. And McCluskey was the reason I went to Princeton. And it was probably one of my better decisions because I couldn't have picked a better place or a better professor to work for.

DasGupta: Yeah. I mean, I know Ed McCluskey myself, and I know what you're talking about. He was quite a legend.

Eichelberger: Yes, he is.

DasGupta: And he still is.

Eichelberger: The thing about Ed that was so surprising is how different he was from so many of his colleagues in a really good way, because he cared about his graduate students about the same way he cared about his children and treated us that way-- with great respect. And when we did something wrong, he treated us the same way he treated his kids. And his favorite thing was, if you weren't working hard, he would bring you in, and he'd say, "Why are you here?" I'd say, "Well, to get a graduate degree." Well, "So why are you here?" He'd say, "You can make more money if you work outside. You're not going to make more money by coming here for three years and working on a PhD. And if you don't want to get that PhD and don't want to work hard, why are you here?" So that was his lecture to anybody that wasn't working. So he was stern, but he was a great professor and he knew what he was talking about, and you could learn from him.

DasGupta: In a way, that sort of answers my next question about the experience that you had during the study that shaped your subsequent career. I think that pretty much summarized what you learned. It's about the hard work, the dedication, the devotion to that particular goal.

Eichelberger: Yes. But what was interesting was my dissertation worked into my future career. And as luck would have it, my first year -- after my first year, Professor McCluskey had a summer job at IBM in Poughkeepsie, and I wanted to follow him up there. But the rule was, on the Resident Study Program, you had to spend 100% of your time at the university. So he was up in Poughkeepsie working for IBM, and I was back working in the library.

But we stayed in touch, and he came back with a thesis topic for me that came from an unpublished paper that a gentleman by the name of John Earl had written. He had read some work that Huffman at MIT had done on asynchronous sequential synthesis. That's how to design asynchronous circuits. And he had looked at it and realized that a simple flip-flop called an Eccles Jordan binary counter-- one flip-flop, one storage element-- used only one feedback loop. And if you followed the Huffman technique for the same function, it would take two feedback loops, or two flip-flops. And he raised the question, "What's wrong with Huffman's technique?"

So that's what McCluskey dumped on my table when he came back. And I looked at it, and it was perfect for what I like to do. And so the subject of my dissertation turned out to be the synthesis of asynchronous sequential circuits, and I was solving it by using hazards and delays, which was another topic in combinational logic. And we were also working with McCluskey on that section of his book. So that was my introduction to hazards and races that we'll talk about some more.

DasGupta: Yeah, sure. In fact, that's a good segue way to my next set of questions. So let's talk about your early career before we delve into some of the later highlights. So my understanding is that you joined IBM when there was quite a lot of turmoil. In fact, when I say turmoil, it's in a good sense. It's good turmoil-- a lot of energy in bringing out new ideas to market, et cetera. So vacuum tubes were giving way to transistors, ferrite cores were becoming popular, et cetera, et cetera. So first things first, which lab did you join in IBM?

Eichelberger: I came to work in the lab in Endicott. It was -- then they called it the Glendale Lab. And that's where I got started. It was a good place.

DasGupta: And that's where Marty Kelly worked?

Eichelberger: Yeah. And I worked for Marty Kelly. And then I went back to school. And when I came back, they were just about ready to announce System 360 and ship it, so I got involved in some of that work at that point. And when I came back, there was a group of people that used computers -- about 20 people. It was called the Scientific Computation Lab. And they were working in everything that was going on in the lab. And so I managed that for the next few years in Endicott.

DasGupta: So what was it like for a young engineer fresh out of college when you graduated from Lehigh and came to work at Endicott-- what was it like to be starting a career with all that energy, with System 360 coming along, et cetera?

Eichelberger: It was a good time to be in the computer business at IBM. Probably the best time. All the companies were hiring like crazy. At Lehigh, every one of us that interviewed in electrical engineering, if we interviewed three companies, we had three offers the next day almost. And they even would raise the starting salary as the time went on. So you could pick and go wherever you wanted. And when I went to Endicott, there were literally 40 of us that had joined IBM in the Endicott area that year. So we had a class of 40 new young engineers. And we became good friends, and some of my close friends in that group of 40, I worked with throughout my career. It was just a lot of fun.

DasGupta: And in fact, they started off with putting you in this year-long training program, right? Which was quite unique at that time.

Eichelberger: Well, they figured none of us had any education about computers, so the best thing to do was try to teach us about it. And that's what we did. We also were given short-term assignments in different locations in the lab so we had some exposure to what was going on. And then they actually cut the year-long program short after about nine months because they felt they needed this talent to actually get out there and do something useful. And so we all got a permanent assignment, and that's when I went to work for Marty Kelly.

DasGupta: OK. So now let's talk of some of the advances that you created and contributed to. So when many in industry talk of you, they think LSSD, or level-sensitive scan design. But as we've discussed, LSSD was just a culmination of a process that started many years ago with hazard-free design. That was certainly the underpinning. So my first question is, when did you first encounter the problem, and what was the first solution that you created relating to, let's say, hazard-free design?

Eichelberger: OK. As I said before, my thesis topic was using hazards and delays to implement asynchronous circuits, so I lived with hazards and delays in combinational logic and how they applied to sequential logic for two years, and ate and slept with them. So I was quite familiar with that subject. And then I didn't think too much more about it for a couple of years.

And one of the bright young men working in the Scientific Comp Lab was also a Lehigh graduate. He happened to be the best tennis player Lehigh ever had, for what it's worth. His name was Lowell Latshaw. And he was so good that we played tennis tournaments all around, and whenever there was a tournament with Latshaw, they ran it differently because they had a Latshaw losers' bracket. Anybody that got beat by Latshaw going to the finals got to play off to play him again.

Lowell was working on a job which was to do the next card testing for System 360 cards that had the electronic circuits on them -- and did the final test on the cards. And these cards were getting more and more logic circuits on them, and they were having feedback loops. And so for the first time, you had to test a sequential machine somehow. And he was writing the final stage, which analyzed the test patterns they wanted to use from another program. He would simulate these programs and generate "measure" commands to measure different outputs and also evaluate how many faults were covered -- traditional way of evaluating a test -- using stuck-at-fault coverage.

And when it all came together and they started testing cards, all the cards that got tested were bad. And they didn't think all the cards were bad. They thought the tester wasn't working right, and the test equipment wasn't working right. And this was very close to where we had to start shipping 360s. And without tested cards, you could not ship the 360. And they thought it had something to do with the sequential nature of these cards and the way they were simulating them, and no one quite knew what to do. It was panic mode, and everybody got involved, and I sat in and listened and followed what was going on and talked to Lowell more about it.

And it occurred to me that since it turned out that the simulator they had was just a binary simulator simulating ones and zeroes. But when they started with a card to be tested, they didn't know what state the feedback loops were in. So you had to come up with a third value for your simulation that said this state could be either one or zero. So it was a three-value simulator already -- one, zero, and the x-state. And they would start simulating with these x's and they would start applying changes from an unknown input to a one or a zero, and then thereafter, those inputs would change from a one to a zero or a zero to one in their simulation.

And if indeed the problem was what we thought – it was some sort of feedback loop ending up in the wrong state and then being measured as a one instead of a zero later on and causing the card to fail test. And it has to do with races and these feedback loops. And it occurred to me that maybe using that x-state a different way might help. So thereafter, instead of simulating a one to a zero or a zero to a one on the input, we just suggested why don't we go from one to x to zero or zero to x to one?

And the next day they tested cards, and they were OK. So suddenly we had three-value simulation to detect hazards and races, and that was kind of new, and I ended up writing a paper about it and had it published in the IBM Journal. And in addition to using the three values to do test evaluation, they also wanted to use it for actually verifying the designs, which we did before we went to hardware. And so they ended up with a design verification simulation that used three-value simulation to detect hazards in the operation of the machine.

DasGupta: Now I gather this happened after you came back from Princeton?

Eichelberger: Yes. I was manager of the Scientific Comp Lab, and Lowell Latshaw was working for me at the time.

DasGupta: So if you look back upon that work, how much do you think your experience at Princeton helped to lead to the solution?

Eichelberger: Well, no doubt about it. I spent two years worrying about hazards and races, and that's what it was about. So it must have had some connection.

DasGupta: Yeah, I would think so. I would think so indeed. So then, of course, we talk about LSSD. So in a way, this is sort of the main course, talking about LSSD. So I have a bunch of questions, so we'll just go through one at a time. So first, what got you thinking of the problem of testing sequential logic? Was it a continuation of your research activities that you were involved in into hazard-free design? Or were you asked to investigate a particular problem to provide fresh insights from your position that you had at IBM then, given your track record of your past success with three-value simulation? So what was it?

Eichelberger: Well, clearly, one of the problems testing those cards was pretty difficult. And we solved it with -- temporarily, at least -- with the three-value simulation so we could test the cards. But the three-value simulation was a conservative approach, and it threw out some good tests as well as all the bad ones. And it was clear that you still hadn't totally solved the testing problem. And I'd been around testing one way or the other, and I knew people that were very involved in testing, so I got more and more interested in testing.

And one of the things that was well understood in the whole subject was that if you had a combinational logic network with no feedback loops-- for every combination on the input, you had an output combination -- that you could write programs to generate tests for those circuits real good. But once you went from a combinational circuit to a sequential circuit, no one quite knew how we were ever going to automate that test procedure very well. And every effort so far they had tried was not very good. So, if you could find some way to simplify the test into combinational logic testing, that would solve the problem, and everybody knew that. But no one was real sure how to do that.

They were looking at other ways as well. So that was well known, and it was interesting enough that my first three years I spent was designing a shift register. Actually, it turned out to be more like a multi-port register because you could come in parallel as well. So that seemed to be a very good way to go about trying to control and observe the storage elements and simplify the problem to combinational logic.

So the work I'd done on shift registers sort of came in. The work on hazards was also relevant because one of the problems with the sequential circuit was everybody did them differently, and some of them worked good, and some of them didn't. And these hazards would suddenly pop up and not work. One example that I didn't even know at the time when I proposed LSSD -- later, when we were evaluating it and we were trying to see how many circuits we could put on a logic chip -- and it was a big debate whether it would be 50 or 500.

And so they had built some test chips in Fishkill and they were testing them. And lo and behold, they were all failing again-- zero yield! And so that was proof that you couldn't build 500 circuits on a chip because we tried it, and it wasn't working.

Well, a year and a half later after that had happened-- and it was affecting the way our plans were going in LSI design in Fishkill, someone tried testing the same chips on a new tester that had faster rise times and fall times, and they found that those chips were mostly good. And the reason was there was a hazard in the latch that would not work right for slow rise times and fall times. So once again, the hazards had come in. So the thought was twofold. One was to solve the hazard problem some way, and the other one was to simplify the problem with testing to combinational logic, and that's what LSSD was basically all about.

DasGupta: Yeah. In fact, it leads to the next question-- is that there were people who were working with shift registers before LSSD was created. So if I were to summarize, OK, this is what was the critical reason why LSSD succeeded and all the other previous efforts failed, would you say it's because it was hazard free, it was level sensitive, and—with a set of rules? How would you summarize that?

Eichelberger: Well, it was taking a lot of ideas that had been around a lot. Everybody knew we wanted to simplify it to combinational logic. Everyone knew, to do that, you had to do something about being able to initialize the latches in your machine and also observe them. And the shift register was just a really good way of doing that. And since I had spent the first three years of my career designing them, it was still fresh in my memory. And it seemed like if you did it that way, the overhead would be in that little shift register. And good circuit design could minimize that overhead, and I knew that because I had worked in circuits. So all those came together.

And we wanted to avoid these hazards. We knew how to do that in general with a clocked system. And all our systems were clocked in some way, but they had different types of latches. And some of them worked good, and some of them didn't. And when you got around to testing, by the time you got to the test group and tried to generate tests, they didn't know where the latches were and where the feedback loops were. So you needed to some way convey to the testers the fact that here are the storage elements and here's how you use them, and use them the same way in testing.

And so that required some sort of standardization in how we do these things. And so a lot of it was standardization of how we do design. And we took designs that were used -- particularly the ones that we used in the mainframes because that was where the big money was, and they had the most power in the company. And we pretty much took that design concept, and we formalized it and extended it.

And in fact, their design was called a master-slave. So you had two latches, one feeding the other, and all the timing was affected by the two clocks that affected those. And if you could hit those clocks properly, you didn't have any race problems. And if the latches were designed properly, you could slow the clocks up, and there was no problem. And the overhead was very small because you already had those two latches in the design, and all you needed was a way of scanning in to the input of the first latch.

And in fact, when we did a study, one of the conclusions that the designers from Poughkeepsie had was that if you needed to log out the status of your machine when it failed in the field -- and that was one of the requirements of the time for mainframes -- LSSD was the cheapest way to do it. So that helped.

DasGupta: Yeah. In fact, I have a question on that, too, a little later. And so if you're talking about standardizing and formalizing, would you say that the fact that there were design rules that guided the designers to design every chip the same way when it came to LSSD was one of the key differentiators?

Eichelberger: Standardization was as important as anything. And the fact that the standardization had some good features that worked solved both the race problem as well as the testing problem helped out a lot. So when you follow those design rules, then it would work in the field. It would also work when you got around to trying to test the manufacturing parts. So it worked both ways.

But the bad part about it was it was a standard, and it was loved about as much as people love driving on the right-hand side of the road and having stop lights and stop signs. Nobody likes that. Not many people liked the LSSD design rules because the most fun about designing networks was designing those latches and the clocking. I had been told by people in the design shop that, "Well, the person in our group that controls the clocks controls the whole machine design." So here we were, the technology house telling the designers how to design their clocks. And that wasn't too popular.

DasGupta: Yeah. I remember that. In fact, as a tribute to those rules, they are still in use at IBM today.

Eichelberger: I hear that.

DasGupta: Forty years later, they are still being used. And I think it's ubiquitous throughout IBM, LSSD, even today. So you briefly mentioned it, but I want to touch on it a little bit more-- is that besides the fact that LSSD was used in manufacturing tests to make sure that the chips were properly tested -- of course, you had to design it, and of course, you had the infrastructure to generate the patterns, which was a big differentiator. There were other collateral benefits that came out of it. You briefly mentioned about system diagnosis. Can you elaborate on that a little bit?

Eichelberger: Well, yeah. Absolutely. And the diagnostics can play two or three roles, and the most important role is when you're manufacturing, particularly when you're into large-scale integration. You were at 500 circuits plus, and you had a lot of storage stuff on the chip. When you built that chip, then you tested it and it failed-- and by the way, a lot of times it failed because the manufacturing was bad. There was a failure everywhere, on every chip they tested.

Now the question is, how do you fix that? Where are the problems? Is it a logic design problem? Or is it some sort of defect in manufacturing? Now the only way to do that is to diagnose where the failure is on the chip. And they developed software that could go in and evaluate this, much like test pattern generation. They actually did fault simulation. And they could pinpoint where the failures were as long as it was done in LSSD. And this was a great help in fixing the process line when it wasn't working right. And then when you put multiple chips on a card or a module, if one of them was bad, you could find out very quickly where it was and do the repair work. So the diagnostic, I think, was probably more valuable almost than the testing end of it.

DasGupta: In fact, that was stretched into the area of not just diagnosing a manufacturing defect, but also, when they were bringing up a new machine, diagnosing it down to a failing replaceable unit-- and they carried it on into the field as well, where the engineer who would go to fix the unit knew exactly what had already failed, right?

Eichelberger: Yep. It certainly was all there. Poughkeepsie, even before this, had techniques where when you had a failure, you would just stop the clocks and then try to look at what had failed. And this, of course, let them do that. And it worked better than they had been doing before, I understand.

DasGupta: Yeah. I understand that technique is still in use today, from what I gather. So that was an incredible achievement, that something that was developed in the '70s is still in use today. Indeed. So how much did the embedding of LSSD into the ecosystem of design technology, specifically in the technology libraries, the software support and design rule checking and automatic test pattern generation, affect the final outcome, in your opinion?

Eichelberger: Well, once everything started working, it was like locking it in. It was hard to get them to do it in the first place, but after everything was running, no one had courage enough to try not to do it. They couldn't succeed. So it just -- it was essential, and it was also part of the success.

DasGupta: Yeah. In fact, if you look at the collateral benefits that you extracted out of LSSD -- so for instance, ATPG, Automatic Test Pattern Generation, become a whole lot easier, right?

Eichelberger: Oh, yes.

DasGupta: And same with reduced testing time, both test generation as well as testing time, reduction in zero yield conditions. So any comments on those, the effects that it had?

Eichelberger: Well, it certainly did all those, and it also set a foundation from which you could then do better things. And the next big step was generally called self-test. And the idea of taking a shift register and making it what they call a linear feedback shift register, where you could then just shift data through it, and it will generate all ”2 to the n” combinations and repeat. And this was a wonderful way of generating pseudo random patterns, and so this became very popular as sort of the next step in simplifying tests.

And as you know, the chip testing equipment in East Fishkill under John Waicukauski, Franco Motika, who did the tester design, and a gentleman that we've both worked with a lot, Eric Lindbloom, who managed this program. And about five people turned out the next generation of tester and test generation software, calling it weighted random patterns using these things. And they were processing all the software for it to get it ready. There were about 1,000 circuits per chip, and they were taking about two seconds of computer time per chip to do all that. And the tests were being applied at machine speeds through those shift registers and just applying thousands and thousands of patterns to these chips in a short time.

Test data was low. Test time was low. Test generation time was low. That was next generation, and it set the stage for work like that. Paul Bardell worked in testing the module, and they did what they call a built-in self-test for doing the module test, and that was a module that had 100 chips on it. And they powered it up and let it test itself. So it became a foundation which you could build on and do bigger and better things as well.

DasGupta: In fact, when you talk about pseudo random pattern generation, it's basically an extension of a shift register.

Eichelberger: Exactly.

DasGupta: OK. There's a mathematical formula that is just simple to implement, and I remember it was like falling off a log, getting the linear feedback shift registers straight out of a shift register.

Eichelberger: Oh, it's a wonderful way to test.

DasGupta: Yeah, indeed. And that's one of the collateral benefits of LSSD.

Eichelberger: Absolutely. Side story-- my good boss Marty Kelly that got me started-- 20 years later, he had been promoted lots of times, and he was now in charge of San Jose lab -- everything out there. He was the file products manager, the top job in San Jose, and that's because he was a great executive and great manager. And I was out doing some other stuff and stopped in to see him in his lab. Of course, he had the biggest office on the site. And he just treated me like an old friend again. And he said, "Eddie I just read your paper on LSSD." He said, "And I found out what it was. It was just another shift register design." He said, "Anybody that can make a whole career out of one idea can't be all bad."

DasGupta: Indeed, indeed. Funny how that was not just one idea. You went and after you finished your work on LSSD, you went on to design a microprocessor. So that's the next thing that I want to talk about. So in a nutshell, what this was was a fully LSSD compatible -- compliant microprocessor, which, until that day, people said, "Well, you can do LSSD for master slice designs and mainframes, but you could never do a microprocessor." So was that the challenge that led you to saying, "OK, I'll tackle that challenge?"

Eichelberger: Well, without a doubt, I was motivated to do it in LSSD for obvious reasons. But I also knew that there were lots of benefits from it, and also knew that we could work on the design of those shift register latches and try to get good circuit design and get them implemented in custom design as best as we can and keep the overhead low. And so it was a help once we did it because we could diagnose problems that we had, and we could do it good. There were no restrictions on doing it well and the way we wanted to. So it wasn't all that hard, and it was very helpful. And it worked.

DasGupta: So in the design of the microprocessor, were there particular challenges here for LSSD that were specifically related to the fact that it was a custom designed chip, or was it a direct application of LSSD?

Eichelberger: Pretty much, it was a direct application. And I did two custom designs, and it was just another LSSD design as far as I could tell. And we were just trying to keep the overhead as low as we could by good latch design. But the second one I did was a four-chip bipolar design.

And there was a lot of feeling that you should not do custom design in bipolar because it was so complicated. And there was a feeling that you couldn't do it successfully. And we had this program going along, and all the people that had helped establish the program with a task force had sort of disappeared, and we were left holding the bag trying to do it. And we had our usual problems getting started. And we had our first chip that was a test chip, but it was going to be part of the four-chip module. And we released it, and they built it-- took about six months. And when it came out, it had zero yield. That's the story of my life, right? No. In this case, however, it was real zero yield.

So, Eric Lindbloom went down to the Diagnostic Group and in 24 hours, he brought back pictures that showed there were five defects on that chip. Three of them were mask defects -- had nothing to do with our design. They just didn't build the masks right. It was a new 5,000 circuit chip. They'd been building 1,000 circuit chips, so it was more complex, and they had some mask defects. And we had two design errors. And it took them longer to fix their masks than it did for us to change the design, so they didn't kill the program.

But because of that diagnostic power that we had, we survived, and the four chips were designed and we had a successful product after that. But had it not been for that diagnostic capability, without a doubt, the program would have died. And I'm sure that happened more than once, but it happened to me, and it was really good.

DasGupta: Sure. Yeah. In fact, it may come across a little bit of a back track because I remember when the 4341 was first announced in Endicott. I remember Endicott was one of the rebellious ones that refused to accept LSSD. They were one of the last groups that accepted it. But when they announced the machine, the lab director himself announced that they had brought up the machine in something like 24 hours, which was remarkable. I don't know if you remember that.

Eichelberger: I did not remember that. I didn't even know that until you told me.

DasGupta: So there's another example of collateral gain.

Eichelberger: Yeah. Endicott was tough. They had two corporate audits on us in the early days, trying to stop LSSD, but they did like it in the end.

DasGupta: Yeah. Indeed, indeed. OK, so I'm going to shift gears slightly because I want to talk about -- any time you talk about breakthroughs, you also have to overcome some major obstacles. So I have a couple of questions on that. So it's generally the case that when one attempts to make major breakthroughs, one is faced with a fair share of naysayers who always impede progress. So without naming names, of course, what kind of impediments did you face when, first, number one, when you were trying to solve the problem of hazard detection and three-value simulation, and even more so in the development and propagation of LSSD?

Eichelberger: Well, let's talk about LSSD because what happened there after we proposed this, I got a job working for a gentleman by the name of Jack Langdon, and he had a group of about 8 or 10 people in Fishkill that were just exploring all the problems, looking ahead at building a large-scale integrated chip, and they didn't know how big it was going to be. It'd be 100 circuits or maybe 500. It was in that neighborhood. And I had written a paper about LSSD -- unpublished, of course -- and he gave me the job of working on testing for the next generation.

And so at that time, the chief architect for the future systems was a young man by the name of Dick Case. Now, Dick Case and I were part of the group of 40 that started in 1956. And Dick Case and I had become close friends. We carpooled together. We did bowling together. We did lots of things together. So we were the closest of friends. But we hadn't seen each other for probably two years. He'd gone his way, and I'd gone mine. And he was now in charge of the architecture.

And so it seemed obvious that it was going to affect the design team more than anybody, so I went to him and said, "How do you want to do this? Do you want to evaluate in some way?" So he said, "Well, why don't you set up a task force?" And so we got a task force with representatives from all the product designers that were going to look at this, as well as technology people. And we made a study of value and cost. And the end result was they decided it was the right thing to do, except Endicott disagreed.

But outside of that, it was proceeding, and we were off and running. And at that point, I knew that this was going to be something different, and trying to get all the people involved in this design standard to work on it, you needed at least someone in charge of the design standard. And so I raised that and said you need a small group of people. And I ended up with the job. And you joined me, and Tom Williams joined me, and Gordie Robbins joined me. So I had a wonderful team of four guys, and we conquered the world. And that's the way that ran. And you asked me what did I do to the people that didn't want to do this right? That was easy. I just picked you and told you to go work on it.

[LAUGHTER]

DasGupta: Thank you. Thank you. But there were a lot of people who were initially quite a bit -- not just against it, but were really leery about all these changes. Change is always a painful thing to do, so these were very painful times for many of them.

Eichelberger: It was painful to all of us a little bit.

DasGupta: Of course, yeah. So how about -- did you have similar problems when you were proposing three-value simulation, or that was sort of like a slam dunk?

Eichelberger: Well, the three-value simulation was a good solution to a problem that nobody else knew how to solve. We had to test cards, so that was welcomed. No one objected to that at all.

DasGupta: That's good. That's good. So do you have any thoughts to share on how you went about solving the technical issues, and how do you solve also the political issues? I'm of the belief that it's political issues that take more time than the technical problems.

Eichelberger: Well, going at the top, getting Dick Case, chief architect, to say this is a good thing to do was the proper way to set the stage. Getting someone worrying about it -- we had to have a coordination group because first of all, you had the designers that had to understand it and do the design. That was the hard part. But then you had the test generation people that were writing software to generate test patterns, and that was not easy! The big joke was that LSSD makes test generation easy. That was the big joke in the test group because it was the hardest job they ever had.

But what it did is it made it possible to do these complex chips, and they didn't know how to do it before. But it didn't make it easy. And then you had the test equipment people, and that was no small part. In fact, when we finally succeeded in getting the mainframe and the bipolar technologies done, you had the rest of the world designing in NFETs and ultimately CMOS, and they were a different world… different manufacturing site, different testing site.

And when you would go to these groups, which you were involved with and Tom very much, later, and you'd try to get them to do LSSD, they'd say, "Well, we can't do it." "Why?" Well, they don't have any test equipment to do it. And so we would go to the test equipment people, and they said "We don't need to build any test equipment because there are no LSSD designs to test." So it was a chicken and the egg issue, and that was a very difficult one to break through. And it almost took some corporate edicts to get both sides dancing together. So that was one of the big problems for the long term.

DasGupta: So looking back upon all these years-- it's been a while-- 40 years, as I said. So if you had to do it all over again, are there things you would have, in 20/20 hindsight, you would do differently in any of these major accomplishment that you had?

Eichelberger: Well, that's a good question, and I wish I had a good answer to that, but I don't. I thought about it a lot since you showed me the question you were going to ask. And I'm sure there are ways to do it better. There must be, but I don't know what they are. I really don't. And that's probably because I was too close to it.

One of the things we did do that I hadn't mentioned that worked quite well, as you remember, is each product group that we went to -- and they were all over the world -- we tried to get, in addition to going there and educating the whole team for a day or two, we asked management to set up and pick one person that became the LSSD expert in their group. And he would work with us. When a designer had a problem, he would go to him. And then if he couldn't solve it, he would come to us.

And so we had a focus on how they were doing, what problems they had, and then we found out there were a lot of problems with the designers. But the problem this designer had was like the problem this other designer had. And so once you solved it once, you didn't have to solve it 10 times. And you could communicate that. So that worked very well and helped in some of the problems. But I have no idea how we could have done a lot better. I'm sure it is possible, but I don't know what it is.

DasGupta: OK, thank you. So now I'm going to switch gears again, OK? This relates to about giving advice to people who want to advance a career in technology. So given your long and illustrious career at IBM, what advice would you give to those considering a career in the semiconductor industry?

Eichelberger: Well, I'm not very good at giving advice. At least that's what my family tells me. So I believe that's probably true. But anyway, some simple stuff that I can remember that is probably the advice my father gave me, which wasn't very much advice, which was if you go to college and study for four years, make sure you can come out. You can get a job. And so to paraphrase that, step one, find a field to work in that has a future. And then, you want to find something that you like to do that you can do well. That's pretty obvious. But those three go together. And the last is the famous line is – “do it.”

DasGupta: Just do it. So but today, engineering has become a whole lot more complicated. So what skills do you think, other than engineering knowhow, do you think you would recommend for people today? Are there additional skills you think they should get, besides getting a good engineering degree?

Eichelberger: I'm sorry. I have no help on that either, really. I don't know what to say. The world is quite different out there, and once again, the world is different, but you've got to see it as it's going to be as best you can and pursue it and do something you like to do well.

DasGupta: OK, so we are getting near the end-- just a couple more questions. So were there any individuals who you'd like to give particular credit to for mentoring you and supporting you at critical moments in your career?

Eichelberger: I think I've mentioned quite a few of them. The one certainly-- my high school wrestling coach, Billy Martin, got me off on a good start. His starting wrestling and teaching me how to wrestle got me an education, and that education got me a job. And I had another coach at Lehigh that was equally good in teaching me how to succeed at it. I don't think that got me a job or anything. But then I had a good manager, Marty Kelly that got me some more education. So my education got me a job, and then my job got me an education. Professor McCluskey clearly was number one! He never stops helping!

Certainly, Jack Langdon was key to the early success in LSSD. He gave me a job and supported me in getting the whole thing started. Dick Case was in charge of the whole show. He was an old friend, but he was a tough manager, and he wouldn't do anything he didn't think was right. But he carried the day. Dick had a wonderful line when there was a lot of fighting going on about what to do, and he summed it up beautifully. He told his team, he said, "Look. There's probably a half a dozen ways to solve this testing problem." He says, "But solving it in a half a dozen ways is not as good as solving it one way."

And he understood the need for a standard that everybody could follow then and probably implement. And we had enough trouble implementing one approach. And we would not have succeeded with two.

[Editor’s Note: The following section was added by Dr. Eichelberger during his review of the transcript.]

> But when it comes to giving credit to people who supported me at a critical time, the top credit goes to you, Gordie Robbins and Tom Williams. You were the team that made LSSD happen! I’m sure you remember the many problems you needed to solve to keep the program alive.
>
> And after the first few years of success with the 500 circuit bipolar chip technology, I left to do custom chip design, you went to get your PhD on the Resident Study Program, and Tom Williams

took over and extended LSSD to the FET chip designs. This was not easy and Tom deserves a huge amount of credit!

Finally, the development of the test generation system for LSSD was new and difficult. The work was led successfully by Peter Bottorff in Endicott. I never knew a better manager or a better person who was better liked or respected by all the people he worked with. Peter had a great team to manage and a key member of that team, Ron Walther, traveled around with us to the many design groups helping them to understand how to design in LSSD and how to use the new test generation system to obtain high quality test patterns.

But if you talk about people that helped, we all were helped by two gentlemen by the names of Tom Watson, Senior and Tom Watson, Junior. And we had a leader that made IBM the greatest company in the world for about 35 years, and his father got it started. I don't think anybody ran a company any better than they did. And even though I never met them, their decisions in running the company had a strong influence on my career and my life.

DasGupta: So in conclusion, any other anecdotes et cetera, that you'd like to mention, both serious and humorous, that made your career exciting that you may not have mentioned as part of the questions that I've thrown at you so far?

Eichelberger: Well, as I mentioned, Tom Watson, Junior -- I mention two things, but Watson's decision to get into transistors and out of vacuum tubes had a major role in my early work getting accepted and, as a result, going back to graduate school. But my going back to graduate school was relative to the second decision he made to send people back to graduate school. So the first two big things in my IBM life were directly out of major decisions that Tom Watson, Junior made. And I just found that kind of interesting.

There was one other thing that happened that might be amusing. I was one of the few IBM “bonus boys”. I told you when we were getting out of college and getting jobs, everybody was giving offers to us. Well, the manager of personnel in Endicott needed to hire a bunch of people that year, as I was told, and so he decided he would one-up the offer. And about the end of February, he sent out a letter to all the people he'd made offers to, telling us that as soon as we accepted the job offer, he'd put us on half-salary until we came to work in July. So that was a pretty nice bonus for somebody coming out of college. And he almost lost his job as personnel manager because of it. He was the only one that ever did it. But those of us who got the bonus award were very nice to him. So when I came to work for IBM, I had a nice, big bonus.

And 38 years later, when times were tough and they were trying to move people out and getting people to retire, they were offering bonuses again. And since I was about ready to retire, I was happy to take the bonus. So I took the year's salary and retired. And so I got a bonus coming in. I got a bonus going out.

But oddly enough, the bonus going out was a lot bigger than the bonus coming in, and that bothered me a little bit.

DasGupta: Any others? That's it?

Eichelberger: That's it.

DasGupta: OK. Well, thank you very much.

Eichelberger: Thank you, Sumit. I appreciate this very much.

DasGupta: Thank you very, very much.

END OF INTERVIEW

