PROFESSOR: When did you arrive at MIT?

ROSALIND WILLIAMS: I was a post-doc in 1980.

PROFESSOR: Yeah, I just remember that.

PROFESSOR: So Ros is also a historian of technology. But she practices the craft a little different than David and I do. She focuses on the cultural side of things and is an expert in literature and what writers have said about technological change and has written a lot about those subjects. But also, she served as the dean of undergraduate education.

ROSALIND WILLIAMS: And student affairs. I did both jobs.

PROFESSOR: I didn't know if I had the title. There was one time when you didn't have two deans. You didn't a dean for residential life. You had them combined in one office. And she got stuck with that job, which is as you might imagine, is a lot of work. And so Ross did that for at least six--

ROSALIND WILLIAMS: Five years.

PROFESSOR: Five years. So that's been a big item on her agenda. And now, she's back in the department.

And today, she's going to talk about chemical engineering basically, in the early 20th century. And this is extremely interesting. She gave a lecture about it last year.

Because her grandfather was Warren K. Lewis. If any of are familiar with the "Lewis Report" of the late 1940s, that's the report that in effect that established the School of Humanities and Social Sciences.

But here's a chemical engineer who is a very much involved and looking at all aspects of life at MIT and coming up with this report. And as they say, the rest is history. So Ros has a long lineage here, that your grandfather goes back to the early 1900s, I would say. Didn't he get here--

ROSALIND WILLIAMS: He was class of '05.

PROFESSOR: Yeah. So she's going to talk about this area. And she's brought some very interesting materials I'm anxious to look at.

ROSALIND WILLIAMS: So I wanted to do something new this time. And that's why in the last hour, I went though my Lewis box. Archives are just boxes of stuff. This is from my attic. And the library's is just not that different.

And I pulled out some little treasures, at least I think they're treasures, that will give you a flavor of what archives are like and when you're doing history, what you learn from archives that you don't learn online, can't learn online. I may overstate that. I may take that back. But I'll stand by it for a talking point.

So I'm going to start with giving you an overview of intertwined biography of Warren K. Lewis and of the world here in the Boston area, Cambridge, and MIT specifically, as they intertwined. And in discussing afterwards, we can talk about him, we can talk about chemical engineering. We can also talk about deanly things.

If you're interested in student life history, I've done a little boning up on that for a documentary that was being shot last week about the evolution of student life at MIT. So I sort of refreshed my memory about some points on that topic. So we talk about anything you want to talk about.

But first of all, let me give you some what my grandfather used to say, you want to put the fodder down where the calves can get at it. So I'm going to put out some fodder. Fodder is food, so cow food. They say you've got to put it down. So I'm putting it down. And we'll chew on this together and then see where it takes us.

So this is this kind of biographical history of chemical engineering at MIT. I remember my grandfather sitting in the living room holding forth, as he was wont to do, in Newton, Massachusetts. This is where he lived with my grandmother and mother and three other siblings. He was a boarder in the household and married the daughter.

And this is a little part history right there. Most MIT students, there weren't residences. So you boarded with families or you were in a fraternity. So boarding was very common.

Let me just me just mention something about his family. You see his dates. His father was born in 1845, in Laurel, Delaware. And his father, my grandfather's grandfather, had been born in the kind of, well, mid to late 1700s. He had three wives. My grandfather's father was the last child of the third wife.

So there's a huge gap in the half-brothers, between Henry Clay Lewis, Henry Clay Lewis, that's the name of my grandfather's father, and the first wife's, first child. Many of these children died.

But this is just a part of history, the fact that if I go from my grandfather, to his father, to his father, I'm back to the Revolutionary War. Because his grandfather had a brother who died in a prison ship, moored in the Hudson River during the Revolutionary War. So it's just amazing to me that you just take a few steps and you're back in time, like that.

This is Delaware. Delaware was a slave state. It was a slave-owning family. Also an abolitionist family, which is a strange combination. But it's one of those, it's a nice idea, but not until I die will I free my slaves, family. And that's what happened.

But his father was one of the two votes for Abraham Lincoln in his county in Delaware in 1860. And his father-- God, these dates don't seem right. Because if his father is born in 18-- OK. It was his grandfather, his last vote was for Abe Lincoln, that's it, in Laurel, Delaware.

If you look at the history of slavery in Laurel, what's fascinating is that next door was Maryland, where slaves could be traded, but not in Delaware, after a certain date. You may know that.

But in Delaware, you could hold slaves, but you couldn't sell them. So there's a huge kidnapping ring, where people from Maryland would go just over the border to Laurel, kidnap either free blacks or slaves, take them back to Maryland, where they could be sold for a huge profit. Because at that time, they could still be sold to other parts of the United States.

So Delaware, Laurel was the site of the Patty Cannon kidnapping ring, which is a fascinating story. But it's not the story I'm here to tell. But it does give context.

This is a farm boy. Kenny was raised on the farm in Laurel, Delaware. Expecting to say on the farm, and his life, he got hijacked by the 20th century. These are just some more pictures holding forth. That's a very familiar pose, very familiar.

PROFESSOR: You know it well.

ROSALIND WILLIAMS: Yeah. I mean as a granddaughter, you knew this guy. Students were terrified of him because he'd get you up here. And you'd start doing something on the board. And you wouldn't know what you were doing and he would pounce.

But as a granddaughter, it was just a very affectionate relationship. I was aware how much he terrified other people. But that was not my relationship with him.

That's the farmhouse, still in a Laurel, Delaware. It used to be a bed and breakfast not that long ago. I don't think it's in business anymore. That's my brother. That's more Warren K. Lewis, Jr., my uncle, and my grandfather.

This is in 1952. He has just sold the farm. Heart breaking, because it had been in the family back to the late 1700s.

But a part of the farm was cut through by a road, the dual, they call it there, a dual highway. Route 14 cut through a corner of the farm and he realized it was never going to be a working farm again. And the irony is of course that part of the reason for putting in that highway is that DuPont had established big factories in northern Delaware. And there's more commuter traffic from south to north.

So chemical engineering, in a sense, destroyed the family farm. And I say there's a sort of irony. There's quite a bit of irony there. Not to mention the fact that the whole automobile age was in part made possible through new methods of refining petroleum, using catalytic cracking, that my grandfather directly worked on.

This is not the best-- but this is the Eastern Shore, this peninsula. The Chesapeake Bay is here. So Baltimore is up around here. Washington is kind of off the map, over here. And Philadelphia is to the north.

But this is the Eastern Shore. And it's Virginia down here. You can't see the map-- the split division. So last time I went, I go to the airport in Baltimore, I drive over the Chesapeake Bay Bridge, I go down to roads, about right in the middle. And that takes me two hours.

So you go from one end to the other in a couple hours. With the dual, you go fast, yeah.

So there is a Maryland over here. Oh, you can see the dotted line, OK. So this is Maryland over here. This is where like Dick Cheney lives now, in Easton. It's very high, upper crust.

And this is Delaware, which is much more farming, much more rural. And then Virginia down here. It's pretty rustic. The Chincoteague ponies, Chincoteague is one of these islands off of here.

So this is a garden spot in the 18th and 19th centuries. It is the truck garden area for the Philadelphia and Baltimore markets, raising mainly corn, fruits, vegetables, peaches, tomatoes, live stock. It's mixed farming. And I'll tell you some more about that as we go on.

But the reason I have this map-- this is from Bob Post-- the railroad comes to Laurel in 1859. And that opens up the whole area to commercial farming much more. I mean it had always been such, but even more.

Now, my grandfather's grandfather was a sea captain. Farming was his-- that's where the wife and kids stayed. But he made his money in the trade, starting from the Chesapeake, doing a lot of trade of the Caribbean. So that's where his money came from.

I mean he was a large, established farmer and the state legislator. So he was a politician. But he was a well-off person for Delaware, but still basically a sea captain and a farmer.

So the railroad comes. And this is sort of getting ahead of the story. But my grandfather born in 1882, he goes through the three-year high school in Laurel, Delaware. And learns everything you learn there, because there's one teacher for all grades, in one classroom.

And his parents want him to get a better education. He's an only child. He's obviously going to inherit the farm. So they want him to go to a better high school than the Laurel one.

So his cousin, she's actually a cousin I guess. He had an older female cousin named Mary Witherby, who had left Laurel to teach school, like her father, and she was teaching school at the Lasell Female seminary, which still exists around here. Do any of you-- you know what I'm talking about.

PROFESSOR: Oh, sure.

ROSALIND WILLIAMS: It's now Lasell College. It used to be junior college, now college. Yeah, and it's in West Newton, just a stone's throw from your place.

So my grandfather was sent up by his parents to live in Newton, go to high school. Newton High was famous even then as a good school. He would board with the family. But he had his cousin in town. And she would look after him and make sure he didn't get into too much trouble.

This house is a block away from where I live now. I go there all the time. So that's still there, one of the older houses in the neighborhood. So this is where he boarded.

Now, I happen to have his diary from his first full winter at Hunnewell Avenue in Newton. And it starts January 10, 1898 and it goes through the spring. So I'm a little mixed up about the timing, because I believe this is his second year I believe at Newton High.

His first year he came up, he got an A in arithmetic, a D in drawing, and F's in everything else. So it was not a good high school he was coming from. And he really had to catch up. By this time, I think it's the second year, he's got his feet under him and he's doing better.

So he's boarding in the winter of '98. And I just want to read a few little details that will give you a sense of what life was like, daily life was like for him at that time. This is the Second Industrial Revolution, is what we call it from up here. But down here, this is what it's like.

After school, this is high school, he says, this is January 12, I went up to Lasell and read Cicero with cousin Mary. Who's Cicero? What does this tell you? You read Cicero in Latin. You start with doing Cicero. You wind up with Cicero and Virgil.

So he's reading his Latin with his cousin. And then she gave me a supper of canned chicken, cocoa, bread, butter, crackers, and peanut butter. I had a fine time.

OK, canned chicken? I mean I don't have to rub this in. You can figure this out. This is not off the farm.

Canned chicken, cocoa, you know we're dealing with the Caribbean at least, if that's not the East Indies. Bread, butter, all right, crackers-- packaged food-- and peanut butter.

OK. So he mentions that-- at home, he got a letter from home. And the letter from home says four factories were going up in Laurel and vicinity for canning. He, my father-- this is my grandfather's father, he is going to put out 10 acres of tomatoes. He has only four cows now.

So there's a lot of agricultural history there. There's a new canning factory, more tomatoes, fewer cows. So just to jump ahead, my grandfather would say that he paid for his MIT tuition when he got to MIT, with tomatoes, sold to a cannery at $4 a ton.

PROFESSOR: Jesus, $4 a ton.

ROSALIND WILLIAMS: $4 a ton. Now, he had the bright idea, during his college years, of recycling. That is, using the tomato skins, which are removed in the canning process, or they tried to remove them, using those skins to feed to the cows as fodder. And they tried it. The cows ate them. But then they gave pink milk. So it didn't work.

OK, just a few more of these from his diary. We're still back in January 1898. Today, as I was walking home from school, cousin Mary in the electrics-- so what are the electrics?

PROFESSOR: Trolleys.

ROSALIND WILLIAMS: Trolleys. OK, the street car suburbs-- this is a little digression. But this is showing how the electric trolley system was being extended at the time. This is the Sam Best Warner's classic study.

And the trolley, which I remember from my childhood, near Hunewell Avenue, where he lived, is just a block away. You can just walk. In fact, now it's a bus system. But it's the same route. And you can get on where we live and go to Fenway Park in one stop.

PROFESSOR: No wonder you live in that neighborhood.

ROSALIND Of course, you got it.

WILLIAMS:

Then we went into Boston. Cousin Mary in the electrics, saw me, got out and walked home with me. Then we went into Boston. Now, this would have been on the train track, which is the other side of the hill that he's looking on.

Went into Boston. And she bought two tin basins, a pie pan, a strainer, and a dozen knives and forks. She carried it in a mug strainer belonging to the coffee pot, to fit the strainer she brought to it. So she's buying a piece for her coffee pot. She's buying all this stuff, taking the electrics into Boston.

So this tells you a lot about technological systems of the day. But I think my favorite entry from this diary, this is in February. He says, I went downtown. This would be Newton Corner. I went downtown in the evening and rode, R-O-D-E, underlined. I asked a man passing, for a ride, and he consented.

It was the first time, underlined, I've ridden, underlined, on or behind a horse since last September, and I a farmer's boy. So there's cars, there's trolleys, there's trains. But he wants to ride the horse, because that's what farmers; boys did.

There's a lot. I could go on and on about what you find out from this diary. There's a lot of reading, Cicero, Shakespeare. There's a lot of magazines. He's reading magazines a lot.

He's going to church. There are church plays. There are glee club performances at Lasell.

He goes into Boston for lectures at the temple, Fremont Temple. He goes to the Museum of Fine Arts, still with us, discusses modern illustrators who are exhibited there. Then cousin Mary gives him some pictures.

But I mean it is an information age, in its own way. It's just a different kind of media. But he's very connected.

So, for example, on January 20, he says he goes into Boston to hear a lecture on imperialism by Dr. Lyman Abbott. Now why in 1898, is he going to a lecture on imperialism? What's going on? What's the news? Anybody know?

AUDIENCE: Spanish-American War.

ROSALIND WILLIAMS: OK? Which--

PROFESSOR: He said it.

ROSALIND WILLIAMS: Spanish-American War, go to the head of the class, yeah. And it's interesting. He says the lecture was a fine one in favor of staying to help them, the Filipinos in this case, learn to govern themselves.

And then he goes to another lecture the next week, same topic, another speaker, who also make good points. But cousin Mary said some bad ones. He attacked, the second speaker, Dr. Abbott, the first speaker, saying he had made some misstatements concerning the arguments on Californian annexation and made McKinley out as having imperial power. So there's debate going on.

And then on February 7, we received our first news yesterday of the Battle of Manila. Reports of dead and wounded, the gunboats did a fearful execution. Then there's Washington's birthday soon after, the church bells ring all day.

And my grandfather writes, these are signs to me that it is the anniversary of the birth of the greatest American, underlined, ever borne. OK, anyway.

PROFESSOR: It wasn't Abe Lincoln.

ROSALIND WILLIAMS: Um, true.

PROFESSOR: It was GW.

ROSALIND WILLIAMS: It was GW.

How about that.

AUDIENCE: [INAUDIBLE].

ROSALIND WILLIAMS: Yeah.

PROFESSOR: Well, her-- yeah, but her-- it would be your great grandfather's-- whose name is Henry Clay. Now, Henry Clay--

ROSALIND WILLIAMS: That's another-- yeah.

PROFESSOR: But Henry Clay was Abraham Lincoln's great idol in a way.

ROSALIND WILLIAMS: I mean the story of this family and slavery is just fascinating.

PROFESSOR: Yeah, it's very interesting, very interesting.

ROSALIND WILLIAMS: Well, I just showed you this paper of my grandmother's, my grandfather's wife, on the Negro problem in 1921. Because my grandfather, he wanted to go back to the farm and improve race relations by starting that farm up again in the right way. And that never happened. But that was the idea.

OK, instead what happens? In the spring, he asked two teachers at Newton High what they thought would be best for him to do about college? They will think it over, he writes. But the former advised either Amherst Agricultural-- what's that?

PROFESSOR: New Mass.

ROSALIND WILLIAMS: Yeah, it's the University of Amherst now, the Ag School-- other Amherst agriculture, or as even better, tech. One of them mentioned Cornell, but tech.

Here we are. So he thinks about it. By the way, this is just a picture of downtown Boston, when they take the train in there.

I was there Friday, meeting my son and his girlfriend. It's not-- they're not people like I know. And I was saying to my son, oh gee, my grandparent's would be so distressed to see this.

And he said-- he has a place in Fort Point, he said. But that's up and coming. That needs to be [INAUDIBLE]. And now, it's happening.

But let me just mention, I mean these are quick reminders that the occupation of engineering was growing very quickly at the time. And that the people who went into engineering-- my grandfather is very typical, in being off the farm and not particularly well educated. This is the way for young men, almost always young men, to have a professional or quasi-professional career, without having to consider postgraduate study, like law or divinity or medicine required.

So here's Boston Tech. You must have seen this picture somewhat, in this class. Here's Trinity Church in Copley Square. This is Boston Tech?

PROFESSOR: It's Boston Tech.

ROSALIND WILLIAMS: Yeah. And I've seen other photos where I can't really place it. So I would love to see somebody do a sort of up to date GPS showing exactly--

AUDIENCE: So that's still there.

ROSALIND WILLIAMS: That's there, yeah.

AUDIENCE: And then across the street from that building is Brooks Brothers, on Berkeley Street, across from [INAUDIBLE].

ROSALIND WILLIAMS: This is all one big building there.

AUDIENCE: Yeah, that's the [INAUDIBLE].

PROFESSOR: There's actually a plaque on the front of that office building

ROSALIND But there was another building, not the Rogers Building, but another building, like off

WILLIAMS: to the side.

PROFESSOR: Yeah. It would be in that direction.

AUDIENCE: There's a bunch of stuff. Mark Jarzombek showed us a map, and sort of to the right of where the photograph is. There's train tracks and stuff there.

ROSALIND WILLIAMS: Now, the steep steps, was that on this building, on the Rogers Building, or the second one?

PROFESSOR: I think it's right there.

ROSALIND WILLIAMS: Oh, there.

PROFESSOR: Right there.

ROSALIND WILLIAMS: Oh, OK. OK. Because again, my grandfather had a story about a kind of a riot involving Harvard and MIT students and a fire and he was on the witness stand. And it had to do with the steps. Some things don't change.

AUDIENCE: Mark talked about the difference between those two--

ROSALIND WILLIAMS: These two buildings.

AUDIENCE: --buildings. But they're separated by a couple of decades. But closer is a custom-built laboratory, where you can see the fumes of the vents coming at the top there.

ROSALIND WILLIAMS: Oh, that has happened here. That's fascinating.

So in the subway spot at Kimball, it says the second building MIT build was a gym, a gymnasium? Does anybody-- I just read it there the other day, thinking that's the first I knew.

So Warren K. Lewis enters MIT in 1901, planning to study chemical engineer--

excuse me, mechanical engineering, still the dominant engineering, kind of the default mode. But he had a friend, this friend that he was boarding with in Newton, whose sister he eventually married, urged him to try chemical engineering. It seemed more interesting and so on and so forth.

So as you know from your reading, something like industrial chemistry had begun. Actually, it was 1888, I think was the first offerings in industrial chemistry. And by 1893, there was a lab.

This is sort of like the first start of chemical engineering at MIT. But then because of deaths and departures, it sort of declined. But just when my grandfather's was entering, actually in 1903, this is when Walker comes back. And Noyes had been there for a couple years. So it's sort of like a false start early on. And then it kind of restarted around the turn of the century. And this is something that he wrote many years later, that I think captures the overall feeling of the time.

Lewis wrote, the stimulus of these concepts, and he's referring to unit operations and these related concepts, the stimulus of these concepts made work in chemical engineering at the Institute from 1902 to the outbreak of World War I an inspiration for both staff and student, which it is impossible to describe.

So these are happening years. I mean the tension between Noyes and Walker is a productive tension. They had each other to play off of. And they certainly did.

By the way, you know Walker, that's not Walker, Memorial Walker. Walker Memorial is named after Francis Amasa Walker, one of the early presidents. Have I got it right?

PROFESSOR: Yup.

ROSALIND WILLIAMS: And we're talking about William Walker. It's no relation. So it's important to those straight.

So you have these two very strong personalities. This is Noyes, trained in Germany, a physical chemist. And really brought in serious chemistry to the program, beginning in 1902.

And then you have William H. Walker, who had also been educated in Germany, Penn State and Gottingen, both. And was teaching analytical chemistry, the partner of A.D. Little, which was originally Little and Walker. So he was entrusted with Course 10 in 1903. And was entrusted with building it up into a chemical engineering curriculum.

Now this, you can't read. But I will read to you, because this is Walker's statement written years later. This was after he had left MIT. This is either from the late '20s or early '30s-- well, he died in the '30s.

So this is his statement of what he was trying to do. It's a fascinating statement. So I'm going to read you what Walker wrote.

What an industry needed was not a man who had been taught what the industry already knew, but rather a man who was trained to do what the industry had not been able to do. The ideal man for the industries was one who had been given a sound knowledge of chemistry and physics. And then as a part of the curriculum, had been given systematic experience in the application of this knowledge to the solution of industrial problems. That he should not be a specialist, but a solver of problems, any kind of problem that industry might present.

And then he goes on to say, this idea met opposition, both from established courses of chemical instruction and from industry. And the industry thought it was too theoretical. But the scientists thought it was too industry oriented. So Walker is on this very nice edge between not trying to give into one or the other.

And then he goes on and says-- this at the top of the second paragraph, I love this-- to prove the soundness of this idea, I returned to MIT in 1903. And after a hot fight with both the chemical and the engineering faculties, I reconstructed Course X as a general educational course without options. And without options, that turns out to be important.

So this is a feisty guy. And I'm sure that's one reason he and my grandfather got along very well. They were both feisty people, very self assured. But my grandfather always would say, it is Walker who invented chemical engineering in this country. He did not claim that for himself at all.

But again, my grandfather studied. With Noyes. You know, I was just reminding you, this is particularly in Servos's article. My grandfather studied with Noyes, took P-Chem from him, and graduating in the class of '05. My grandfather's is this kind of this grim-- he looks-- kind of a grim looking guy. And you'll see another picture. I'll pass it around.

In the spring of his senior year, he expected to go back to the farm, as much as you and I expect the Sun to come up tomorrow. However, he got a job in the lab, I think with Noyes. And then that led to somebody, I don't know whether it was Noyes or Walker, one of them suggested that he apply for a traveling fellowship which was being offered. And it was $1,000 stipend, which is that day and age was a lot of money.

A traveling fellowship, he could go anywhere for a doctorate. And so he really was not interested. But one of them basically appealed to his competitive spirit and kind of said well, if you don't get it, somebody else is going to get it. And $1,000 sounded very nice.

He applied, got it and was on his way to Breslau, in what is now Germany, it's kind of on the Polish-German border, for graduate school the next year. Later, he found he was in fact the only applicant that year.

PROFESSOR: Well, it's interesting. Think about what the Harvard class of 1905, where they might have chosen to have their picture taken.

ROSALIND WILLIAMS: Aah.

AUDIENCE: I'm sure it was not in the laboratory.

ROSALIND Yeah, yeah. I mean this is a good example, where it tells you so much. It does.

WILLIAMS: Began with the names and faces.

AUDIENCE: Books piled up in the front of them.

ROSALIND WILLIAMS: Yeah. So--

AUDIENCE: What's in the books on the front?

ROSALIND WILLIAMS: Yeah. Oh yeah, that's great.

So this is his dissertation in German, from Breslau, three years later. He wrote it in Florence, because he thought Florence was the most beautiful city in the world, and why not write your dissertation there? I recommend that highly, if any of you write dissertations. But this is Germany. And just keep that in mind when we get to World War II.

PROFESSOR: Yeah, yeah.

AUDIENCE: World War I.

PROFESSOR: And he was sufficiently literate in German to be able to write a dissertation.

ROSALIND WILLIAMS: Yeah. Yeah. Well, he never felt his German was that great. And in fact, back to Latin, a story he tells us taking the train to Italy, or maybe back from Italy. But in any case, he was seated next to somebody-- maybe they were like Polish or something. But German didn't work. The other person didn't know English. So they conversed in Latin.

PROFESSOR: Is that right?

ROSALIND WILLIAMS: You never know.

PROFESSOR: It's fascinating.

ROSALIND WILLIAMS: It may come in handy. So then he comes back to-- well, he has a year working at a tannery in Manchester, New Hampshire. And as a result of that experience, he always said tanneries do not have to pollute. It's not necessary, if you run them right. And they don't have to smell either, that's the other thing you associate was a tannery.

So he comes back. And you can see how chemical engineering around 1910, there's this kind of reversal of who was majoring in what. And this is before the war. Because when World War I comes, even before the US enters World War I, the Great War, in 1917, there's a tremendous demand for military equipment. And chemical engineering is connected with gas warfare, which was used right near the beginning of the war.

It was in the spring of 1915 that chlorine was first used on the battlefield as a poison gas. Chlorine is not the most effective, by any means. It dissipates pretty quickly. But the surprise factor was such that it really did work in the initial use. And it had a tremendous psychological effect in scaring people on both sides.

So Walker, William Walker, was put in charge of the Edgewood Arsenal, once the US entered the war, to manufacture toxic gases. And my grandfather was put in charge of gas defense. So he worked on the masks.

And there's all sorts of-- I mean this is very specialized equipment. And to try to design equipment that made it possible to keep fighting and yet would protect the soldier from poison gas, not just the soldier but-- do I have some of the-- the animals too. In fact, there's a whole long story about the horses being affected by mustard gas, which is a vesicant. And it's a much nastier gas. And it would affect the animals too.

So the one story that I need to tell you about my grandfather and gas defense, this made such an impression on me. We had this conversation was I was a teenager. Let's see, he said there was not a single Allied soldier-- am I taking too much?

PROFESSOR: No, no.

ROSALIND WILLIAMS: It won't take much longer. There's not a single Allied soldier is World War I who died from poison gas when they had the gas mask and other equipment on. And I grandpa, you must been so proud because you designed something that was fail-safe. It worked every time. And he said no, it means I over designed.

And what he meant was the cost of putting on a mask is quite high. It's makes it hard to breathe. And it does encumber you. So in designing the gas mask, you have to make it just on the edge. Because then, soldiers are more likely to put it on in the first place. So by over designing it, it meant that he was surmising that more people had died but not putting on the mask at all. Because it was such a pain to put on.

And for an engineer to think that way about human life, it just really took me aback. And I thought, boy, that's responsibility. After he died in 1975, you clean out the house of the person who has passed on. And down in the cellar, big basement, in the furnace room there are these shelves. And there were all these gas masks lined up on the shelves.

And it turned out at the end of the war, the Allied troops have given him a model of each of the gas masks that had been used by the Allies in the war. So he had this collection of gas masks that were just sitting down there. And I called the Smithsonian and I called the MIT Museum, and I said I think this is really interesting. But nobody took the gas masks. So they have thrown out, because I tried. I tried.

AUDIENCE: You weren't tempted to just mount them on wall in your living room?

ROSALIND WILLIAMS: Well, they're odd. Well, I mean we'd been looking at pictures from Japan, testing children. And when you get in a haz suit, it's really scary. It's just very curious, period. So no, I was not inclined to keep them around. I was just surprised somebody didn't want them.

Well, actually now I can go back to gas masks for a minute. You've read about the tension between Noyes and Walker, Walker finally leaving.

My grandfather finally becoming head of the chemical engineering department in 1920, known as Walker's protege. But also the real appreciation for the science-based engineering. And the more I read Servos's article, the more I would love to look at his headship of Course 10 in that period. I think it's a really interesting story. I don't know it. But I'm almost sure it's there.

OK, he it comes back. Heads the department for 10 years, but that isn't what he wants to do. He's not an administrative type. He doesn't like it. He loves teaching and he's famous for his teaching. And that's where he really made his mark.

But he did a lot of consulting for what was what was then Standard Oil in New Jersey, Esso, Exxon. And one thing your articles didn't mention I think is the relationship between the university and industry through consulting work and how that fits into the picture. And he was a great believer in the value of consulting. That's how you find out what's happening in the world and it keeps you on your toes. And it's also useful for industry.

So he, to his death, he got a check every month from Exxon. I mean it wasn't a lot, but it was a retainer. And he died at what, 94. So they were very loyal to him and vice versa.

So this is a drawing of the catalytic cracking process. Let's see, have you been to the MIT Museum exhibit? You must have been.

AUDIENCE: I have.

ROSALIND WILLIAMS: OK. And you go through the whole thing. And just when you're going to leave when to go out of the exhibit in that back room, on the left, is a picture of my grandfather and a couple other gentlemen at a refinery in Venezuela where catalytic cracking has been put into production in 1939. And there's a barrel above there, an empty barrel I trust. But anyway, just to make the exhibit about catalytic cracking.

But the timing, 1939, means that once the war broke out in 1940, the demand for aviation fuel was huge. I mean catalytic cracking began as a way to get higher octane for automobiles. And it was the automobile race that instigated it.

AUDIENCE: Does everybody know what catalytic cracking is?

ROSALIND WILLIAMS: So let me give my brief, nontechnical-- actually this is very interesting. He did the work in the basement of Building 12. And you need some kind of a catalytic agent to promote the cracking. It's usually a powder and its mixed in with the petroleum to get more higher octane fractions or lighter weight fractions out of a certain amount of petroleum.

So if you have the same amount of petroleum and the cracking works efficiently, you get more usable high octane fuel than you do without it. So you have this--

AUDIENCE: You take crude oil, basically, and separating out all the parts.

ROSALIND WILLIAMS: It's part of the distillation process. And a higher octane means you can run engines faster and get more power out of them, without knocking and so forth. You know when you need higher octane, if you fill up your car and your car starts knocking. That's a sign that things are not going well. It's true in cars. It's true in airplanes.

So they were trying to blow the catalyst through the petroleum stream. But as a pattern, it kept settling out. It didn't stay mixed in with the stream. So after months and months of work, on trying to get it to hold into the stream, my grandfather, who was famously profane, said damn it, let it settle out.

And in other words, if you let it settle out, then you get a fluid bed at kind of the bottom of the reactor. And it mixes the fumes, the petroleum fumes with, or gases, with the catalyst, better than if you try to blow it along with the stream. So it's fluid-bed catalytic cracking that he and his students are known for and brought a huge fortune to Exxon, which is one of the early adopters.

What he never imagined was that-- again, it comes on line in 1939. Within a year, the tankers are going to Venezuela to fill up with a high octane aviation fuel, going to the docks of Liverpool, and pumping the fuel into the tanks of Spitfires. They don't even put it in the holding tank. They put it right in the tanks of the airplanes. And the Spitfires go up to do battle in the Battle of Britain.

So it's a dramatic example of what you do and then how things happen to change the implications of what you do, that are entirely out of your control. That of course is also the story of the Manhattan Project. When the Manhattan Project got under way-- do I have any slides about this? Oh, this goes back, OK-- basically my grandfather is asked to head up the series of committees making recommendations about the extraction and refinement of fissionable material.

In other words, the chemical engineering problems of the atomic weapons, they require high grade ore, high grade uranium or plutonium. And how do you get it? That's an engineering problem. That's a chemical engineering problem.

So if you go to the MIT archives and ask for Warren K. Lewis material, a lot of it is still classified from World War II, but there is a notebook that he kept when he was going around to, trying to figure out-- I think this is 1941. When was the chain reaction started? '42, right, in Stagg Field, Chicago?

AUDIENCE: Chicago?

ROSALIND WILLIAMS: Chicago. Was that earlier?

AUDIENCE: Earlier.

ROSALIND WILLIAMS: It was earlier.

AUDIENCE: Before the war I think.

ROSALIND WILLIAMS: In the middle of this notebook, appears that event. And he's going around to DuPont, to Oak Ridge. He's going out to Berkeley, Lawrence Lab, talking to all these people, trying to figure out how to do the refining to get the material that they would need for these weapons.

And he served on a series of committees. Was gone all during the war, kind of overseeing the construction and the development of these vast facilities, especially at Oak Ridge, also out in Hanford.

AUDIENCE: If you look at the Manhattan Project, which my favorite statistics would be the size of the US auto industry at the time, a huge project, less that 10% of it is concentrated at Los Alamos or [INAUDIBLE]. Brilliant physicists are-- and most of it were chemical engineering plants in Tennessee and in Washington state, huge plants making the actual material.

ROSALIND WILLIAMS: So he told his wife, my grandmother, just don't ask where I am. But if you need me in an emergency, you call General Groves in Washington, and gave her the phone number. And again, I presume the students have already heard this, but my mother was married in 1940 and I was born in 1944. So this was kind of like the next generation was coming along.

And my mother tells me that when she heard the Lowell Thomas announcement of the bomb being dropped on Hiroshima, on the radio, she said now I know where pop's been, all the war. And I'm a baby. And we're back to Japan these days.

OK, I have to think he was deeply troubled by his role in the Manhattan Project because he didn't talk about it. He talked a lot about World War I and gas masks. But World War II, he just-- I mean I wish I had pressed him more, but I didn't.

My mother said that after the war-- for example, at those days if you got a watch, a wrist watch, and you wanted it to glow in the dark, they put a little radium on the dial just to make it glow in the dark. And he would scrape it off. He didn't want any of that stuff near him. Anyway, so I'm surmising.

But he chaired the Lewis committee, and you'll hear a lot more about that, kept teaching at MIT. My husband had him as a kind of senior thesis adviser in the early 1960s. And there's a lot of letters that he wrote about the role of the engineer and civilization, the profession of engineering.

And this quote from the Lewis Report I think really captures-- I mean we don't know who actually wrote it. Maybe it Morrison or somebody. But he really believes that. He said, if I could come back, it would be as a social scientist, because that's where the big problems are, the really intractable ones. I can see after World War II why you would say that.

So that's the-- yeah, the Spring Garden farm again. OK, so back to the farm. So what I did in about 15 minutes before class was just go through my box of stuff. And I'm just going to pass this around. Obviously, just collect it back there, when it gets back to you.

The point is what you learn from archives that you don't learn from reading articles or so forth. Monthly Report, Laurel City Schools, Laurel, Delaware, Report of Warren Lewis, 1895. This tells you sort of, not only what his grades are, but what they're teaching.

PROFESSOR: Is that the original document?

ROSALIND WILLIAMS: That's the document. Why do I have this stuff? I have no idea.

I gave a lot of it to the archives. And they have copies of this. And I kept a few original documents. There's a lot more. I mean I am from a very literate family. I don't know how else to put it.

Now Ross Basset told you about going through MIT yearbooks and looking at where people are from?

PROFESSOR: A little bit.

ROSALIND WILLIAMS: This is my grandfather on the left. So this is what Ross was looking at, hometown and list. My grandfather's list is very brief. But again, I just thought you'd like to see.

And Breslau, here are photographs of Breslau, where he studied, got his Ph.D. I mean it got bombed to smithereens in the war. None of this is here anymore. But this is old Germany.

PROFESSOR: Did you ever go back to try to visit there?

ROSALIND Not Breslau, no. I think it blew all to smithereens.

WILLIAMS:

PROFESSOR: Probably nothing to see.

ROSALIND WILLIAMS: And I had a couple of bigger photos, that are really beauties, that I have framed it at home. And here's his dissertation. I'm not sure, my German not being workable. But it's signed Rosalind D. Kenway, from Warren, July '05, that's my grandmother.

The Tech, special chemistry and chemical engineering issue, 1910. So remember that chart showing chemistry is going down and chemical-- so this is published at that time. I have no idea why I have this, but I do. And it's so interesting. Few industries not founded on chemistry, it says.

Now, this is a Xerox. This is his father basically selling off the stock of the farm, public sale of valuable cows. And this is what his father writes in 1917, back in Laurel, Delaware.

I have sailed life's storm-swept sea for 74 years and I am now nearing port. I smell the land. It is wise that I should take in-- and I can't read it. But it must be take in the sails-- Therefore on-- He's going to sell his milk cows. This is the start of the decline of agriculture in the United States right here, the family farm.

This is the high school, now Newton North, Newton high school kind of review magazine. This is 1918. A lot of young men are going over to Europe.

But it talks about a Newton high school scientist. Of the many capable men on the defense side of chemical warfare service, perhaps none has contributed more practical ideas that Dr. Lewis. This is his high school, hall of fame, kind of. This is page 10.

My kids went to the same school.

PROFESSOR: Newton North?

ROSALIND WILLIAMS: Yeah, of course. OK, this is March 5, 1920.

PROFESSOR: Of course.

ROSALIND WILLIAMS: You got to show spirit.

PROFESSOR: Of course. Boy if live in Newton, there's a difference. I know that.

ROSALIND WILLIAMS: A different Newton. It matters whether it's north or south. OK, Debbie K. Lewis, required Course 10, 1920. His time here seems very interesting.

AUDIENCE: [INAUDIBLE].

ROSALIND WILLIAMS: Well, actually I won't pass this around because he-- well, maybe I will. This is Spring Garden farm. I showed you the photo actually earlier.

OK, here we have-- oh look, August 5, 1946. Anybody know what happened on August 5, 19-- you know what happened on August 6, 1945? It's Hiroshima. A year minus a day later, James R. Killian writes to Dr. Compton, during the summer, there have been a number of discussions of the need to promote here at the Institute, more interest in the study of educational objectives and procedures. This calls for the Lewis Commission essentially. And it's a letter saying Lewis should head it. And here's some people who should be on it, and here's the budget.

And then a second letter, outlining in more detail what the Lewis Commission would do. It follows shortly thereafter.

Then I just have a bunch of, again my grandfather's thoughts about the history of chemical engineering; engineering as a profession; my favorite title, "The Place of Engineering in Society and Civilization." This is from *Tech Review.* And I thought you would enjoy this title, "Chemical Engineering, A New Science," a new science, 1953.

And so these are all published in one form or another. But then there are letters. And there are quite a few letters to me, to my mother, to my father, when my father's trying to figure out-- this is 1945 and my father notes that at GE, so many younger engineers are getting offers from small companies and should be thinking about this? And my grandfather writes this long letter back, in long hand.

In 1970, somebody has asked him for conversations. He wants to discuss the fundamental differences between Greek philosophy and modern science on the purely intellectual level. And he wants me to come up and help him write something about this.

And this is very moving because he says, I am getting older and it's hard for people to understand me. You, however, have heard enough of it over the years so you know at least the direction in which my mind is working.

PROFESSOR: Ah, interesting. High compliment.

ROSALIND WILLIAMS: Yeah. It's a huge compliment. Anyway, if you don't get the personality, you're missing things.

Thanksgiving dinner. Actually this would be 1963, the fall of 1963. So what happened in the fall of 1963?

PROFESSOR: Oh, Kennedy.

ROSALIND WILLIAMS: It was right after Kennedy's assassination. And my grandfather is saying grace. I remember this like yesterday. He had his usual grace and he gave thanks for the American family, because in such difficult times like these, that's the rock on which the country is founded, the American family.

This is my then boyfriend, between me and my mother.

PROFESSOR: It's not Gary.

ROSALIND WILLIAMS: Yeah, yeah. Have you see the actual Lewis Report?

PROFESSOR: I have never seen that.

ROSALIND It's nice, nice binding job. And this is *A Dollar to a Doughnut,* which are stories about

WILLIAMS: my grandfather's teaching. And this is what the chemical engineering department put together for him when he retired as a feitschrift, because they felt the normal, staid one was not appropriate for such a character.

PROFESSOR: What year did he retire?

ROSALIND WILLIAMS: Well, this is the official retirement. So this is like 1950 or so. But as I say, he's like Leo. He just kept teaching.

This is a CD. Just so you know, in the archives they have-- this is from tape, the original tape, now on CD. At the 50th anniversary of the Department of Chemical Engineering, so in 1970, he gave a talk about reminiscences and the fascinating history of chemical engineering in the 19th century, where he has a whole theory about the time lag between discovery and implementation, both in electrical and chemical engineering. For example, the role of batteries in running the telegraph system, which I had never thought about it as an incentive to chemical engineering.

ROSALIND WILLIAMS: Oh, very interesting.

AUDIENCE: You know the great mentors of the chemical industry that got [INAUDIBLE]?

PROFESSOR: No.

AUDIENCE: Paper making. A lot of early involvement. [INAUDIBLE] to some degree, much less than they were a national center of paper making. A lot of the early MIT chemical engineers were with the paper industry.

ROSALIND WILLIAMS: I didn't know that.

And this last thing, and I bring this along just in serendipity. This is an obituary in 1975. He died on March 9. This is the *Tech Talk,* when we used to have a printed MIT newspaper.

But what struck me as I was picking it up, OK, an obituary. And then I look on the back of the first page, "Response Awaited on Proposal to Train Iranian Nuclear Engineers." And it just struck me, this is why I love hard copy. Because you' come across things you don't plan to come across.

And this is a reminder of this is happening. And of course this had my attention, but on the back we were being friendly with Iran. The Shah was still around.

OK. So that's my show and tell. Do you have any questions?

PROFESSOR: Yeah. Thank you for bringing all this stuff.

ROSALIND WILLIAMS: Well, I just love stuff.

PROFESSOR: It reminds me that I think historians have a special feeling for stuff like this. But I remember when I was working on my dissertation at the National Archives, I was writing about a topic that dated back to the end of the War of 1812. So it was a long time ago.

And I was getting materials out of the archives that were still bound in the original red tape. And you'd pull those strings apart and they would disintegrate. I don't know, it's a weird feeling thinking that I'm the first one to look at the stuff in over 200 years.

ROSALIND WILLIAMS: It's kind of creepy, but it's also exhilarating.

PROFESSOR: Yeah, it is.

ROSALIND WILLIAMS: Exploration, right.

PROFESSOR: And then we had a colleague that Ros and I knew, and I think you may have known him too, David. His name was Brooke Hindle. He was the former director of the Museum of American History at the Smithsonian. But he wrote an article one time called "What is a Piece of the True Cross Worth." Do you remember that article, about the importance of artifacts in the study of technology particularly?

ROSALIND WILLIAMS: The story is that they had four children, two daughters, two sons. The other daughter, besides my mother, Mary, married a guy named Cherry Emerson, who went into plastics after World War II. Plastics, and to quote Chambers, made quite a bit of money in chemical engineering. And he studied with Doc during the war.

So he gave the money to renovate the library, naming it in honor of my grandmother, Warren K Lewis' wife. And he always claimed it was because she loved music so much. And I must say I never heard her listen or talk about music.

So I think it was more Cherry's love of music, than her's. But that doesn't matter. I think it's a great library. And I think my grandmother would particularly be happy that students can sleep on the couches there. She's a very gentle soul.

AUDIENCE: Does anybody here have parents who went to MIT or other relatives? So one think you do see is, any institution that lasts this long has this kind of family connection. Universities are sort of famous for keeping track of that sort of thig. And that's true among faculty, as well.

And there's the genealogies of our blood families. And then we'll talk a bit about this, but not to much explicitly yet. We'll talk about it in the second half, the academic genealogies of so and so's teacher was so and so's student, was so and so's student, was so and so's student.

And then our colleague, Leo Marx, who was my teacher, Who said that, how does it go? His adviser from Harvard in the '40s-- it's only two steps back to Ralph Waldo Emerson. You can trace four academic generations today from Leo Marx to Ralph Waldo Emerson.

I'm sure there are people here, some of the senior faculty who were students of your grandfather's.

ROSALIND WILLIAMS: If I go to Chemical Engineering, they just-- oh, Warren K--

AUDIENCE: And that's a person who started here in 1896. And more than 100 years later, there are still that person's students around.

ROSALIND WILLIAMS: That's been a great been pleasure of university life. It's a sense of continuity. I mean it would drive me crazy too.

PROFESSOR: Ros, your grandfather was born in Delaware and pretty much raised there. He obviously was a religious person. What persuasion?

ROSALIND WILLIAMS: I think in Delaware, he was Methodist.

PROFESSOR: Methodist. Yeah, that makes sense.

ROSALIND WILLIAMS: And one of the most fascinating books I have is of an uncle of his who was a Methodist circuit rider in Delaware, in the 1850s, setting up black churches. They were separate,--

PROFESSOR: Really.

ROSALIND WILLIAMS: --but setting them up. Oh, it's fascinating.

And my grandfather then joined the Congregational church up here, Elliott church in Newton. Because Methodism up here is a little different from what it was in the South. But you get the point. It's a low church. It's not Episcopalian. And he taught Sunday school every Sunday, as long as he could. And his religious faith meant a lot to him.

He was not a fundamentalist, at all. He said, I take the Bible seriously, but not literally. But I mean he knew his Bible up one side and down the other. And it was really fundamental to him.

In his old age, he became good friends with John Crocker, who was the Episcopal chaplain here at MIT. And they had a lot of talks. And I mean again, I think maybe whether it was guilt about the Manhattan Project or just trying to kind of talk about matters of faith and other matters too. So Crocker led his funeral service, which I was glad that he was able to do.

So I think religion is one of the great untapped kind of untapped, unappreciated sources of motivation at MIT. And I don't think my grandfather's unusual. And it's not necessarily any particular religion. But people from outside MIT are always amazed to find how strong the religious groups are here and how many there are and how active they are. It's not their vision of MIT, but it's very true. OK.

ROSALIND WILLIAMS: Well, thank you very much.

PROFESSOR: Thank you very much.

PROFESSOR: OK, I want to just talk today a little bit more about the '30s, the '20s and the '30s. And again, kind of like Ros's talk, use a specific case of a particular faculty member and a particular machine to illustrate some of the general ideas about where MIT moved between about 1925 and 1935 and why that's interesting. And you of course know from the readings, and the more you look at this, everybody says it and the more I read about it, the more you really feel like Karl Compton coming here in 1930 was a major turning point.

There was this kind of internal warfare. What was the word that Lewis used, hot fights about the relation of science and engineering. And the Corporation definitely has an opinion about it. And one thing they do-- they don't have a lot of control over the faculty, but they do decide who the president is.

And so they bring in Karl Compton. He's 42 years old-- and it probably sounds old to you. It sounds young to me-- in 1930.

And one of the young people who was already here was this guy then Vannevar Bush, who we've also heard about, and we'll hear about a bunch more, who was a young electrical engineering professor. And he was building this device called a differential analyzer.

And what I want to do today-- this is again, a sort of prototype for what a paper topic might be, is to look at this instrument and how this instrument was handled and how the instrument itself changed as the goals of the Institution changed, from the '20s through the '30s. So here's Bush and there's the analyzer.

And when we go to the MIT Museum, one of the 150 objects is that part of the analyzer that's in the wooden box there. I'll tell you more about what that is. But it's sitting right there on the front of the floor. And when I was first doing this research, I asked them if they had a piece of it and they didn't really know. And Debbie Douglas and I went back in the storerooms and we found that the original integrator was there.

So if you go into the 1920s, Bush is here. He's a young professor. He had gotten his Ph.D. here. And he was a student of Kennelly, who I mentioned before, who was Edison's assistant. And they were very much in the kind of technology plan world of MIT, solving problems for big industrial partners.

And what is the problem that the big industrial partners are having? Well, in the electrical world, and you've got to remember electrical engineering for a-- how people here are Core 6, in one way or another? OK, so about a third. Electrical engineering, for its first 100 years, really was electrical, without a lot of electronics or any of that solid state physics or certainly no computers and stuff.

It was building big machines to make big generators, and big generators, transmission lines, large electric motors, to drive factories and other kinds of things. And anybody ever hear of the IEEE, Institute of Electrical and Electronic Engineers?

This is a little bit of trivia. But there was the AIEE, American Institute of Electrical Engineers. Those are the big electric power people. In fact, in German universities they still divide the curriculum into big signals and a little signals. And so big signals was the AIEE. Little signals was the IRE, Institute of Radio Engineering, lots of little tiny, little small signals.

And in 1964, they merged in the IEEE. It's to electrical and electronic engineers.

Even though it's probably one of the two major professional societies for computation, but the word "computer" doesn't appear in the title at all.

And so, this is back in the days of electric power. And the problem with the electric power industry is the electric generators start out as basically local phenomena. A local entrepreneur will build a generator, either a hydro plant or steam powered, in one way or another, in a town. And they'll create lighting in the town and maybe run some motors in factories.

And it's all centralized and it was all nonuniform. Every town had a different voltage, a different frequency. Some of them were running on direct current versus alternating current. These are all big battles they were having at the time.

But over the course of the teens and the '20s, those systems are becoming standardized and they're becoming connected into what today we would call grids. So they have a big electric power grid. And they're not quite national yet, but they're very much regional.

And so in the '20s, General Electric starts to build a big grid that brings hydroelectric power from in Canada and also from Niagara Falls, through very, very long transmission lines, hundreds and hundreds of miles, down into the New York City area, which is where most of the population and most of the energy usage is from. And those lines begin to have problems.

And the problems are, if you've got either a lightning strike at one part of the line, you had a bad electrical storm, or even if you had a short circuit and part of the grid tripped off and had just to sort of save itself, you'd get these transients on the line. And the transients would travel great distances. They were just like big wave power spikes on the line and create blackouts all over the place. And there a couple of famous blackouts that happened in the early '20s that really caused a big problem.

So this was like a critical issue about how do you figure out, how do you model the performance of these systems under this kind of stress? And General Electric, and this has come up in the readings in places, had a very close relationship with MIT.

There were a lot of young engineers who would go there, what they called on-test, to Schenectady. In fact, that's where Ros's father worked. I don't if she mention that, Doc Lewis's son went to Schenectady and worked for General Electric. And then they would come back to MIT sometimes, to get a master's degree. And they began looking at this problem of how do you understand these systems.

Now, Bush had done earlier work in his career, which was also based on this whole idea of modeling. I may have mentioned this before where-- how many of you have taken an engineering class where you use a spring mass damper system and model a RLC circuit with it? Ring a bell for anybody? OK, maybe a few too many times. Or, there are other analogies, different kinds of hydraulic analogies.

Well, that whole idea basically comes from the first book that Vannevar Bush wrote, which is called *Operational Circuit Analysis,* where first of all he applies a thing called Oliver Heaviside's operational calculus. Anybody ever heard of the Heaviside step function? And Heaviside was a sort of somewhat outlandish English engineer around the turn of the century, who came up with these ideas. Mathematicians didn't like them because they couldn't prove they were valid.

Heaviside just didn't care about it at all because he could show that they were useful. And they told you a lot about how transients go down lines. And Bush really took the Heaviside work and he put it on a rigorous mathematical foundation.

And said among other things, you can use these analogies and you can model a second order system in any of these different fields with a set of equations. And that can be either RLC circuit or a spring mass damper or there are also hydraulic versions of it, I'm sure any number of other ones.

And what that basic idea allows you to do is to make models of different kinds of circuits. And so what they said is here's this electric power problem. Let's look at this problem and let's build a model of it. And what this thing is, is called a network analyzer. And this picture is probably about 1927.

And all it is, is-- well, first thing they make a model of just the electric power line between Niagara Falls and Boston. So there might be a couple of generators on the line in Niagara Falls, then there's a long transmission line, then there's a whole bunch of different users, and maybe you make one circuit that's 50,000 times smaller than the original. And you use that as a model.

And anybody know what the big problem with that was actually? The hardest thing about making these small models was measuring the output. If you go to the actual electric power system and you put a voltmeter on the line, that voltmeter is going to load the line by some amount. But it's negligible, it really has no impact.

If you make it 50,000 times smaller, you've still got the same voltmeter. And you put it on the line and it's the equivalent of like putting a whole factory on the line. And it affects the performance of it in ways that it wouldn't otherwise.

So it's one thing to make this model. And they did that rather successfully and it helped them describe. And they then reported the results to GE, this is how the thing would behave under a lightning strike. And these are some strategies you can take to make it a little more robust.

Well, once the word out about that, all these different power companies came and said, we would like you to model our system. And so what did they do? Did they constantly build a new one for everybody's power system? No. They built a little set up. Actually, I don't even have to draw it, because it's here.

Where they said OK, we're going to put a bunch of models of transmission lines and a bunch of models of generators and a bunch of models of other things. And they're actually connected together by telephone plug boards. And you bring your system here and we'll plug it together in a certain way, much like a telephone operator connects circuits. At that time, it was done manually. And we'll create this thing.

And this thing, they actually called it a network computer, which is a nice word for it, that comes up later in MIT culture, about 50 years later. And electric power companies would come here. And students would write their theses by designing this system and describing it for a particular power company. And saying here, I modeled your circuit.

And this thing actually was around until the '50s, it turns out. We'll talk about it getting shut down when Gordon Brown shut it down. But it was again this kind of classic MIT in the 1920s, early '30s, model of close relationships with industry, solving very particular problems, almost in a literal consulting role. Tell us what your issue is? We'll model it and we'll help you solve the problem. So we read a lot about that.

Then there was another approach, which was to calculate the progress of these transients directly. And how did they do that? Well, they could do it analytically with algebra. It was extremely difficult because it was not easy to write the equations. But it was much easier to build an analog computer to model it.

And it turned out, and you probably recognize this, that the integral of the product of two functions is a critical piece. Today, you find it in all kinds of signals processing and convolution algorithms. And they said we'll build basically these machines that will model the key function of it.

And this is an early version of it, which is also a specific machine modeled to evaluate the specific integral. They called it a product intergraph. And it didn't use equations at all. It just took curves in and drew curves out. There you can see Bush.

This is actually the output device, which is a watt/hour meter. Why would they use a watt/hour meter from an electric utility? Because a watt/hour meter does the same thing, right. It evaluates the integral of the product of the current. And the voltage is the amount of power that you get billed for. So they take this thing and they just stick there.

And then there's these kind of funky mechanical linkages. And there's all these people involved. And actually they have big high-power resistors, so they use a-- anybody want to guess what that thing hanging up on the top is?

AUDIENCE: Radiator.

PROFESSOR: Close.

AUDIENCE: Radiator.

PROFESSOR: It's a radiator, from?

AUDIENCE: Model T.

PROFESSOR: It's a radiator from a Model T Ford, that they're using to provide cooling water to this machine, which evaluates this particular integral for this particular electric power problem.

In fact, some of these are Bush's students. This one particularly is a guy named Harold Hazen, who we will talk about later. In fact, he's also the guy sitting in the middle there, in that picture.

Here's another picture of it. You can see the watt/hour meter, just taken right out of an electric power measurement facility. Again, you sort of work with what you have. They were working with electric companies. They had these electrical things, a whole bunch of different motor and gears and interconnections. And this was probably in Building-- somewhere in the main group. I'm forgetting exactly. Building 10, I believe was this lab.

I liked, you still have the pencil sharpener there. This is probably the one part of what was in the lab that you might still find in a laboratory today. There's a picture of Bush with it. You can see he looks pretty young.

And so there's the first product intergraph, is this device. And what it does is all those little graph chart holders basically, move under these three independent needles. And the operators just follow the first two curves and then the output plots the integral of those two curves. So it's literally a graphical user interface for an analog computer.

And then, they actually bring it up to one more level of complication. And there's a way that you can make it solve a differential equation, as well as just evaluating an integral. And so this thing is called the second product intergraph, where it's the same kind of thing. There's two different pieces and then you can sort of tie the output back to the input.

And this is about where things stood when Karl Compton becomes president of MIT. And Compton basically says, we're not going to do that kind of stuff anymore. It's too focused on just one problem. It's too simple.

And Bush responds in a very energetic way. And he builds this machine about 1931. And this is called the differential analyzer. Anybody ever heard of that term before? And really it's kind of nothing more than this, but made in a fully general purpose way. Or like I mentioned before, they did with the simulator, they first started building a custom one and then they built a general one.

And what you see here is, these guys here are called integrators. That's the core of the problem. Again, it's primarily an integral thing you're trying to evaluate. An integrator is nothing more than, they call it a wheel and disk integrator.

There's a disk that spins around. In a mechanical sense, that's just a transmission, but a continuously variable one. Then there's a wheel that sits on the transmission. And if the disk is spinning at a fixed rate and the wheel goes in and out, the number of turns on the upper end of wheel is the integral of the curve of the position of the wheel that pulls it off.

But it's a very simple idea mechanically, very hard to do that in a way that is mechanically robust and very accurate. And that's the piece-- actually it was so critical to make it accurate, they covered these with those wooden boxes. That's the piece that's in the MIT Museum.

And then there's all these other elements. I may have a picture of it. So there are all these other elements. You can take these integrators and then you have a multiplier, which is nothing but a gear that connects one rod to another in a ratio. And you have these rods that go through the middle. They're almost like the bus on a computer.

And you can connect these things in all different ways to evaluate a particular equation. In this case, this is just a second order equation for a falling body problem. But you can mix and match this thing and essentially program it by rebuilding it around these connecting rods.

And so, I'll show you a couple of pictures of the-- oops. Here is another view of the integrator. Here you can see the disk and the little wheel that takes off. It actually has a real knife edge on it, to try to make it accurate. One of the real problems with those integrators is that they can't drive much of a load. If they slip at all, they lose a lot of accuracy.

So here they have put these things called torque amplifiers, which are these very clunky, exotic, kind of cached in like devices that amplify the torque. And then they connect them in. And where you might have in an electrical analog computer, there's a voltage that gets pushed around, in a mechanical analogue computer it's just the rotation of these shafts that carry the data from one place to another.

And they do that by going into this matrix of mechanical rods that you see over there on the left. And each time they wanted, they could kind of reprogram the whole thing. And here's another shot. So here's a gear ratio that would perform the multiplication. You can see that this stuff is beautifully machined, very interesting and carefully done. Yeah?

AUDIENCE: And they were doing this in the electrical department.

PROFESSOR: This is in electrical engineering department, right.

AUDIENCE: It seems very much like a mechanical project.

PROFESSOR: It does seem like a mechanical project. That's a very good point.

And Bush actually said, he was very clear, he said, I want my engineers to be able to design mathematical equations the way they design circuits. And he tried to make a circuit design-type language, visual language-- I redrew this picture. But I redrew it from one of their papers. It's the same terminology-- that you could actually design these equations and make these big kind of systems.

And already you're beginning to see a move toward generality. So he says, this is not a device to evaluate integrals for studying transience in the electric power industry. This is a research device for a general purpose calculating machine. And it's interesting, he goes to the Rockefeller-- well, I'll cover that in a minute.

So already you're beginning to see this guy beginning to think in a more general, kind of fundamental terms, as opposed to in these specific terms. And this is within just a couple of years of Compton coming here to MIT.

Here's the output of the device. You can see it's basically creating a family of curves. And they were very into the fact that they didn't need any algebra. They didn't need any equations.

They said the world is basically analog. They didn't use that term. And said, the world is continuous. Our integrator is continuous and produces continuous outputs.

And again, you can see this kind of graphical user interface. There's a little magnifying glass there. And he's kind of following these curves, which was a kind of manual input. Bush is kind of looking over the shoulder there. And they would evaluate all these different kinds of curves.

Here's another view, where they're all connected by an electrical audio system. And there's one guy in the center, telling everybody OK, follow your curves now. And here, he's not doing it by hand so much anymore. He's turning a little crank to trace all the curves. And you can begin to see by the curves, they can do some pretty complicated things.

And there's a whole kind of science of analog computing that comes up in the '30s around these machines, where they measure the number of integrators the way you would measure the number of megahertz of processor that you have in your computer. Because the integrator was the expensive thing that kind of described what order equation you could possibly model with these things.

And people start to use them to model electron orbits in atomic physics. They used them particularly for ballistics. The Army gets really interested. And they have to calculate ballistic equations for all different kinds of guns and shells. And this makes it a lot more convenient. And so you begin to see the move away from, even with the same research group, the same people literally, from this kind of specific industry oriented work toward more general work in what they think of as a general purpose computing.

This is kind of the most famous picture of the device. And you can see there three integrators inside their glass cases. Those integrated became so precise that you had to have them covered, free of dust, and really very well protected. And it turns out there was a integrator that was developed secretly by the Navy for controlling the big guns on battleships, that was better than this one, that they weren't really aware yet.

And has nobody ever see a tubal integrator? It's a whole other kind of mechanism that you can use to do mechanical integration.

So then this project spurs a whole bunch of different other kinds of projects. One is called the cinema intergraph, where the idea is instead of integrating with these kind of problematic mechanical integrators, you integrate using this exotic new technology. Anybody want to guess what that is over on the left? It's a photo cell. And they would actually plot the mathematical curves as images on this 35 millimeter film. And then shine a light through it and plot the area under the curves by integrating the charge that came through the photo cell.

And this is the guy who made it. As he said, it was mostly a machine for producing dissertations. It had essentially no practical output. But it was important in that, this guy is named Gordon Brown, who is a student of Harold Hazen, and becomes the dean of engineering right at the end of the Second World War. And is the guy who closes down all that old-fashioned electrical machinery.

We read about him a little bit. I think it was in the [? Laquier ?] article. And kind of is the dean of engineering when they kind of formalized a lot of things after the

Second World War.

And there's another picture of the cinema intergraph. Also one of his advisers on there was Norbert Wiener, who was also very closely related to Bush's work. And a lot of his earlier ideas of cybernetics also came out of this work.

This is Harold Hazen again. It's called an automatic curve follower. And his idea is, gee, maybe I could make these photo cells just follow these curves automatically. And today, you can go to the Science Museum and buy a little robot kit with a robot that follows a line across the floor. This is the first one of those.

But what's much more interesting and important than that about this, was that in order to do this and order to make the differential analyzer work, it's the amount of friction that builds up in the mechanisms. And it gets to a point where you basically just can't turn the crank anymore. And you start to lose a lot of accuracy.

You don't lose it in the gears. Eventually you would, because they would break. But you lose it in all these other systems, particularly the integrator. So what they do is they put what they call followers or servomechanisms between the stages, where they can kind of renew the signal and add energy to the system.

Because with a mechanical system, if you don't have any energy, it's just going to eventually-- the energy is all dissipated. But if you can carry the data from one point to another and just add energy and make it constantly stronger, you can build them as big as you want.

And it's between that problem and this problem that Hazen actually writes the first paper ever on what he calls the theory of servomechanisms, which you now what know as feedback control theory. And anybody take a course on that, or probably in every engineering course you're taking something in feedback control theory. And he became interested in these basic problems.

Until that point, people had governors on steam engines. They had different kinds of regulators in this electric power network they were working on. But nobody had thought of, let's write about the theory of how this feedback mechanism works overall.

And there again, there's another one of these, a little more detailed example of an intellectual way that Compton's move was not just administrative, he didn't just say let's stop working with industry and think about science. He actually influenced these people in their labs very quickly, within a couple years, to start thinking about fundamental problems as opposed to just these kind of immediate problems.

Hazen also becomes dean of engineering at MIT during the Second World War and head of the electrical engineering department. Here's his model of servomechanisms.

Also in that group, looking at again this electric power problem, and saw something literally in the electrical power problem that was bigger than simply the immediate problem. Anybody want to get who this is? Let me describe what he's doing and maybe then you'll guess?

So you can actually see in this picture, he says, I'm going to look at these generators. And the problem is when they have these transients of these-- they fall out of step, so that in an A/C system, everything has to be running in perfect synchrony. And if it's not running synchronized, you get all kinds of issues.

And he says, I'm going to tape cardboard N and S. So that I'm going to tape them to each of the poles on the generator and then let the generator spin really fast. And then I'm going to shine a light on it and I'm going to pulse the light at exactly the same frequency as the generator is supposed to be spinning.

And that will freeze the N and S in your eye when you look at it. And then if there's a phasing problem, you'll see the N and the S moving back and forth. Now, anybody want to guess who this is?

AUDIENCE: Edgerton.

PROFESSOR: This is Edgerton, right? And this is the first application he have of this stroboscope. And very soon, he says hey, you know what, this stroboscope thing is really interesting. I can make some innovations there. Forget about electric power stuff. I'm interested in high-speed photography and generally high-speed electrical discharge.

AUDIENCE: It's like the first timing light for a car.

PROFESSOR: Yeah. It's exactly the same as the timing light for a car. Most of which are made by EG&G, which was Edgerton's company.

And so there again, he gets interested in a bunch of different things. But all of them have in common this idea of like how even most of the flashes-- you don't see it so much in your digital camera, with the little teeny ones. But if you ever have a big flash, it fires and then you hear it charging up.

And then it fires all again. And Edgerton really became an expert at very rapid discharge of electrical energy. I work a lot at the Undersea World, where Edgerton did a lot of work with sonar. But the particular kind of sonar he built was very much like the flash bulb, in that it was a sonar that flashed the sound. It's called side-scan sonar, rather than continuous wave sonar, would just gave it all the time.

So for the plutonium bomb in particular, the one during World War II, and I think they still are spherical, and you had to implode this device. And a guy at Harvard, Kistiakowsky, made these explosive lenses. And you had to trigger them all around this sphere at exactly the same moment. Otherwise, you were going to get a lopsided shock wave and you weren't going to implode the thing perfectly. And it was Edgerton's company that designed the triggering mechanisms for that atomic bomb.

They also did high-speed photography of the actual mushroom clouds. And it's amazing, sort of frightening imagery that they've collected all through the Cold War about that.

And that was EG&G. It was founded by Edgerton, Germeshausen, and Grier, two of his colleagues. And the-- let's see, what is it-- Building 37 is the building they gave. And there's a Grier room and the Germeshausen room. And I forget which the auditorium is called.

But that work started here. And then Edgerton developed that. And interestingly, one of the students, a guy named Marty Klein, who is the sort of the father of that side-scan sonar, is a good friend of mine. And he always says, Edgerton was a time domain man. He never thought in the frequency domain. For those of you who are EEs, you'll know what that refers to.

And that really came out this legacy from Bush's lab of thinking about transience on these lines. There's nothing to say about electric power systems in the frequency domain, because it's all 60 Hertz. It's all exactly the same frequency, unlike radio which is all about frequency domain.

He thought in the time domain. And everything about the electronics-- anybody work in the Edgerton lab these days or take a class there? All that stuff is time domain stuff, kind of epitomized by the high-speed photography.

Here's an image again of the Army getting interested at the Aberdeen Proving Ground, down in Maryland, which did a lot of the measurement for ballistics. They bought five or six of these or they hired people and they made their own copies of them. Within a few years, during the '30s, they were all over the place, not just in electric power. Yeah?

AUDIENCE: When do you begin to see military funding of this work? Does it start with Bush's differential? No, OK.

PROFESSOR: Really not until the war. So I'll come to the funding issue in a second, because it's pretty interesting.

They also, with Bush's consulting, built the control system for the Palomar telescope, which at the time was the biggest telescope ever built. It didn't even become operational until after the Second World War. Anybody ever been there? It's in California, outside of San Diego.

And you have this enormous, three-story high telescope. And you've got to point it with great accuracy. And it actually had a lot of similarities to the problems they were working on there.

So there's also a funding story here. Warren Weaver is also mentioned in the-- I'm forgetting if it was the Servos or the [? Laquier ?] article from the Rockefeller Foundation. And they talk about it.

It was [? Laquier. ?] He said, as soon as Compton came in, he went to the Rockefeller Foundation and said, I need $175,000 for this new initiative. And if you guys back me on this-- at the time, there was no National Science Foundation. There was no public money other than from the military, available for research. But the Rockefeller Foundation was basically the equivalent of the NSF today, a private foundation handing out these checks.

And Bush went to Weaver. And he went to Weaver with this early version of the differential analyzer. And it was about 1931.

And Weaver says, not interested. That engineering stuff is best handled by industrial funding. We don't support anything that looks like engineering research. We only support fundamental research. Why don't you go find an electric power company or somebody to give it to you?

Two years later, Bush goes back to Weaver and says oh, this is not a machine for electric power research. This is a machine for fundamental research in computing. And Weaver says, oh, well if you're going to put it that way, here's $100,000.

At the depths of the Depression, that a lot of money for a research program, far beyond what anybody-- in fact, I think there's a statistic in there that before the war, the entire federal funding for all of MIT was only $40,000 a year. And they gave Bush, not just $100,000, but about $250,000 in the middle of the '30s, to build the next version, which became known as the Rockefeller differential analyzer.

And here you see, it looks a little bit more sophisticated. Instead of those earlier tables, they called them input tables, here you have a rotating drum. There's still a person required to sit there and turn the handle. But the basic model was a lot more electrical.

And also interestingly, the operators of these machines changed from men to women. So they're no longer graduate students operating them. They're much more what they called human computers at the time, operating them.

But you can see there, a similar idea. There are curves on this drum. The person looks at the curves and is providing the input to the machine by matching the pointer to the curve.

And the way this machine worked, is also really interesting. A lot like the other one, but instead of that matrix of circular rods in the middle, it's a crossbar switch. Anybody know what industry a crossbar switch comes from? It's a telephone switch.

And its electrical switch that basically says, I got all these inputs across the top and all these inputs across the bottom. I can connect anyone to anyone, in fact in this case using a punched paper tape. And so they get the prototype crossbar switch from Bell Labs. It was a pretty big revolution in telephone switching at the time.

They had built this crossbar and donated it to MIT. And what they did was they said, we're just going to adapt each of these mechanical elements-- in fact, the integrators were still mechanical-- but we're going to give them electrical outputs. Instead of the quantities being represented by the rotation angle of the rod, it's now represented by a voltage.

We'll feed all the voltages into the crossbar switch. And then you configure the crossbar switch by reading a paper tape into it. And so you can basically model any equation by some set of switch closings on the crossbar switch and you program those by a paper tape.

And now, you're beginning to see the beginning of digital switching coming into -- there wasn't even a word for "digital" at the time-- coming into this idea of analogue computing. And so then the problem for the programmer becomes, they have this continuous analog equation across the top. I need to translate it into these paper tapes.

And that's kind of an interesting problem, how do I think about the transformation from a set of equations into a set of switch closures? And this young master student looks at it and he says well, I can actually make this kind of-- he calls it a relay algebra. And I'm going to design a little kind of mechanical notation that will allow me to design these circuits.

And you know that totally useless stuff that I studied in mathematics they called Boolean algebra, from the 19th century, is actually kind of useful here. And I'm going to call a closed switch, a 1 and an open switch, a 0. And that allows you to manipulate the whole thing mathematically.

Anybody know who this is? You maybe the name flash by.

AUDIENCE: You mean Claude Shannon?

PROFESSOR: Yeah, it's actually Claude Shannon, writes his master's thesis on exactly this problem. And many people call this the most significant master's thesis ever written in electrical engineering. The master's thesis basically lays down the entire groundwork for the design of digital systems in 1936 and based on the problems that are raised by designing this computational machine.

And he immediately gets hired by Bell Labs and starts to go work there and think about how to design switching circuits. And the kind of counterpart at Bell Labs right at that moment reads this thesis and says, I'm going to call this kind of electronics digital. And actually invents the word "digital" to describe that kind of electronics.

So here's a case of-- again, 1936, Karl Compton has only been at MIT for six years. But he's already pushed this particular laboratory and this particular set of students to start thinking about their work in a different way. Much less specific to one industry specific to solving particular applications, and more generally thinking about the fundamentals, the mathematics, with applications to lots and lots of other areas.

So that's just one case there, I thought I would show you. And then, all those people are also then people who get very involved in the early digital computing. Once the war starts, basically they all go to Washington with Bush.

Some of them stay here and get very involved. But we'll cover that in the next time we actually meet.

Questions, comments about that?

AUDIENCE: Is that the same servomechanism laboratory that goes and creates the Whirlwind?

PROFESSOR: Yeah. The earlier question, it's exactly that laboratory. So Gordon Brown starts the Servomechanism Laboratory in 1940. He the first course ever on feedback control theory at MIT in 1939. And he writes this one paper. In fact, it's called "Transient Analysis of Servomechanisms." So it still carries that transient idea from the early electric power work.

And Warren Weaver shows up in his lab and says, guess what? I work for the government now. I don't work for the Rockefeller Foundation anymore. That paper that you just wrote, that you're about to publish, it's classified. You're not allowed to publish it anymore. And here's $500,000 to start your lab.

And Brown sort of takes it in. And if it happens for an historian, very valuable that they classified that paper. Because then, anyone who got a copy of it, had to sign it out. So he writes this fundamental paper. And then you can actually trace week by week, out in the community, who's reading the paper and see how they are changing their work.

And they begin to have this idea, again if you look at feedback control, there's governors on steam engines. There's regulators on arc lights. There's automatic pilots in airplanes. And is even feedback amplifiers in electrical engineering. But there's nobody who says, hey, you know what, all that stuff is really the same.

And now, we take for granted as that's what you study in control theory. You don't study any one of those areas. You study the basic phenomenon. And that was the beginning of what Brown was doing.

And it was really a coincidence that right about that moment, it goes underground and it stays underground for the whole war. And that's really where when Norbert Wiener comes out in 1948, and says, cybernetics, feedback control, it's all about this, he was just saying something that had been secret for eight years already at that point.

But one of the things that got me interested in this research was, why was MIT's first digital computer made by the Servomechanisms Lab? Because you don't necessarily associate those two things in your mind. A servo, you think of as an analog, mechanical thing and a digital computer as this funny electronic thing. But during the war, it sort of-- it actually happens after the war, but right after the war.