The Science Studio: Interview with Leon Lederman

ROGER BINGHAM: My guest today in the Science Studio is Leon Lederman, Director Emeritus of Fermi National Accelerator Laboratory or Fermilab. He won the 1988 Nobel Prize in Physics with Melvin Schwartz and Jack Steinberger for the discovery of the muon neutrino and he's the founder of the Illinois Mathematics and Science Academy. So Leon, welcome.

LEON LEDERMAN: Thank you.

BINGHAM: We talked yesterday a great deal at the conference about the science of educating and this is one of your passions. Would you like to tell me what you think the state of science education is in this country or in general?

LEDERMAN: Well it depends on how you count it. If you count the efforts to improve it, it's enormous. There are efforts going all over the country; clever people, well meaning people, experienced people, amateurs, parents, concerned citizens, scientists worrying about the state of science education. So it must be something they're worried about.

And if you take stock of our system, there are various ways you can do that. You find disquieting information everywhere you look. Cities are still doing poorly. Poverty still governs the pace at which you can beat it by educating poor kids in the city. We're not doing a very good job there. We still have our very bright people. Somehow they manage to cope with even schools that are not appreciative of their talents and a lot of them survive and are rescued in the better high schools and universities.

But if you hold to any of the international measurements that compare student bodies, we're down there in the lowest quarter or third in some places. Especially our seniors in high school who are, in fact, purposely and voluntarily studying science scored way down in numbers, 16 out of 16 nations.

The international tests are very good; there is a lot of criticism that they don't test fairly. But all of those criticisms have been answered by serious educators who are trying to make a measurement of the success or failure of educational systems. Now we're down there with Slovenia someplace and we're not doing well for one of the richest countries in the world. I guess we're not rich anymore. We're a debtor country, right? We're the poorest rich country in the world.

We clearly are not doing well and our industries recognize this. There's a distinct air of concern about whether we can cope in this 21st century with the science and technology that's bounding forward ever more rapidly. If we can't keep up with that and we can't supply our rational industries, the IBMs and Microsofts, Motorolas and so on. We can't supply them with good scientists and good engineers and good technicians, there's going to be a suffering in this country.

BINGHAM: But what happened? Let's go back a little bit before we talk about the solutions and so on. So you were born in 1922 in New York, where did your parents come from, what was their background?

LEDERMAN: They came from Europe. They were European immigrants. My father came when he was 18, my mother when she was 14 or something like that. They met in New York but they were part of this large immigration from Eastern Europe that followed World War I.

BINGHAM: From Russia?

LEDERMAN: Yes, they came from Russia.

BINGHAM: I think I read somewhere that your mother arrived with a little tag on her.

LEDERMAN: Yeah. With a name and address of some relative of hers that was going to find her when she got off the ship and pass through immigration in New York. She somehow survived all that and there was Leon. He went to school with his older brother Paul and we went to school. I don't remember too much about the public schools except that I enjoyed them, they were interesting fun. And I kept looking for ways to impress my teachers.

I remember one weekend before Christmas, the last day of school before Christmas and a Santa Claus came to the room. And all of the kids were very excited. This was probably kindergarten or first grade. I said that's not really Santa Claus I can see he's wearing a mask. The teacher said shut up, or words to that effect, don't spoil it for the other kids.

BINGHAM: Early scientist.

LEDERMAN: Early scientist. So my school was very good, I think the teachers were very good. This was post The Great Depression that savaged the country in the 1920s, especially with the '29 Crash. Having a job as a teacher was a very, very good job; it was secure. They were relatively well paid. They were working and so I remember high school was very dramatic. We had moved out of Manhattan to the farming suburbs called the Bronx. There were cows and chickens and so on and farms there. The subway line had just completed and we lived almost on the shores of Pelham Bay in eastern Bronx. The school was very good. It was a few blocks from our house, the high school. Teachers were, I remember, enjoying classes very much, enjoying math.

We were very impressed by a very young lab assistant. That was his job; he cleaned the lab and prepared the laboratory experiments for the students. And we spent a lot of time with him back in the lab and he taught us how to blow glass, make glass structures and use our hands. He said that was very important. He was studying for a PhD in night school and working in the daytime at the school. He made a big impression. I always considered that the younger your teacher is the more you will pay attention, the closer they are to your age.

And in fact, probably the biggest influence on me at most times was not so much the teachers were positive but I felt the students. Some of them were more experienced than I was in the world way. My best friend, his mother and father were teachers and they would go to Europe in the summer. And he was very knowledgeable on the real world and he inspired me. He talked to me. He knew a lot more about the world and he read more than I did. I remember being very moved by him.

BINGHAM: So that whole influx. I talked to other people like Richard Axel, Eric Kandel and there's this whole influx of people running away from something.

LEDERMAN: That's right.

BINGHAM: And being in the States and growing up in that area.

LEDERMAN: Rolling up their sleeves and contributing.

BINGHAM: Going to Columbia and so on. Was science always something that you were attracted to?

LEDERMAN: I remember I was turned on by a book written by Einstein. I think it was written for children, he had a co-author. I don't remember his name. I think the book was published around the '30s and it was very inspiring. It compared science sort of detective story. There are clues, a bloody glove, a white Ford, a barking dog. Those weren't the clues he had but at the end the butler did it and every clue was accounted for. He said science is like that, the world is full of clues as sort of mechanisms of how the world works. And by studying those clues you have to come up with a story, a story which says here's how it was in the beginning and here's why all these things happen. Here's why the day is 24 hours long and the earth spins on its axis and goes around the sun. You're looking always for the simplest explanations for the clues you see.

BINGHAM: But then they get complicated. There was a poll down in England last year in the newspaper. They asked them some simple questions, why is the sky blue? Why does salt dissolve in water? What happens when you switch a light on? How old is the earth? Things like that, you would think people would know or have some sort of a sketchy answer for. And they gave these questions to a panel of scientists and science writers and people who should have known the answer. And they were fairly ludicrous answers, most of them.

LEDERMAN: Is that right?

BINGHAM: Yeah. So, why is the sky blue is not an easy question.

LEDERMAN: It's not an easy question. In fact, that's a good example of how we can get kids to be interested in atoms, more abstract explanations. Because you have to discuss colors, the blue, what is blue and why is this tablecloth blue? Well white light is a mixture of all colors and if you absorb the red out of the scheme, like the chemicals in this dye that swallows up the red and will reflect the blue. So it's blue because of that so that's the story of it.

Then you can ask the question if you're really nasty and say how does the red absorb the colors. And pretty soon you're led down to atoms and the structure of atoms and the fact that they're these oscillating electrons that produce the color.

If they oscillate in one particular way they might get red and another way you'll get purple. It's the structure of atoms that is the basis and almost the answer to all those questions.

In some ways, almost all those questions you ask give you a narrow explanation, which comes down to atoms. And then of course if you're not satisfied you can say what about these atoms? How did they get there, what's their explanation? And then you get down to another level of explanation.

BINGHAM: Pretty much you bank on the big bang in the beginning of the union.

LEDERMAN: That's right.

BINGHAM: Which you are present at?

LEDERMAN: That's right. That's a good answer to a Congressman who says why are we spending all this money. It's always a good question and I think the profit of answering these questions is so enormous. But it shouldn't really be continuously asked. You always have to continue educating; never stop explaining how science works because it is somewhat subtle and takes effort to keep explaining it. But the lessons, the profit of learning how the world works is huge.

BINGHAM: So you mentioned Einstein, you actually met Einstein once.

LEDERMAN: Yes. That was a funny thing. We had a powerful 30-second conversation, the two of us.

BINGHAM: How did that come about?

LEDERMAN: Well I was in graduate school at Columbia studying particle physics. My friend was studying quantum theory at MIT. A mutual friend of ours was down at Princeton at the Math Department and he said, I met Einstein's assistant and if you guys want to meet Einstein, come down to Princeton and I'll tell you what to do and you'll meet him.

BINGHAM: Wow.

LEDERMAN: So we quickly arranged to meet down at Princeton, we went there, we saw our friend. He showed us a bench to sit on and he said the master passes by here with his assistant going to lunch everyday about 12:15. So sit here and you'll get introduced. We were just so nervous. Waited and sure enough, along came the old man. That was roughly 1950.

BINGHAM: Do you remember how he dressed?

LEDERMAN: Oh yeah. With a shabby sweatshirt and sandals. He traditionally never wore socks so we spotted this as he came towards us. And as they were getting close his assistant said would you like to meet some students. Yah, he says. That's the German accent, yah.

BINGHAM: Okay.

LEDERMAN: Otherwise he would have said yes but he said yah. So we jumped up and he asked my friend, well what do you do? And his friend says I'm doing a thesis on quantum theory. Einstein shrugged and said something we were not too surprised about because his opposition of quantum theory was well known. He said you're wasting your time, smiling. So I felt better because I'm doing an experiment on pion, pi mesons, a brand new kind of particle. He said what are you doing and I explained to him that we have an accelerator and we're making pi mesons and we're understanding the properties of these new particles. He waved his hands and he said we don't understand the electron, why do you bother with these other particles? He said goodbye, good luck boys and he keeps walking.

He had disposed of us both in about 30 seconds but we were in cloud nine; we had spoken to the world's greatest scientist. His aura is enormous and if ever doubt it and you go read what he achieved as a single person, the special theory of relativity and the general theory of relativity. He was so far. He was alone out there in the territory of explaining the world in a way no one else did.

The 20th century has two pillars of physics. One is relativity theory and the other is the quantum theory. The quantum theory was developed by a huge number of people, Neils Bohr, Schrodinger, Heisenberg, Bohr, Plunk, Einstein also. All Europeans and all were contributing something to this new theory, which by late 1920s gave us a tremendous, powerful way of understanding atoms.

Data from the atoms just began to appear in the late 1800s. The electron was discovered in 1897. When the electron was discovered by J.J. Thompson in England, the English dons would always have a toast. They would say ladies and gentlemen, let's drink to the electron, may it forever remain useless. However, Mr. Congressman, the electron wasn't useless. In fact, it's the basis of all of our modern technology. Followed by the quantum theory, which explains its behavior in atoms, it probably accounts from some huge fraction 92.7% of the gross national product. Incidentally, 85.3% of all numbers are made up.

BINGHAM: I read somewhere that your actual ambition was to be a stand up comic and you just sort of drifted into physics.

LEDERMAN: I had to do something between jokes to pass the time.

BINGHAM: You talked about the twin pillars and stuff. But if you pick up any magazine now, say a popular science magazine, it's baffling to most people in terms of the debates going on within physics. Is there enough dark matter in the universe to stop it from flying off the edges of the table? Is string theory correct? The debates there are still roiling. What's going on?

LEDERMAN: The frontier is always tentative. And at the frontier, because it's a frontier by definition there are many different points of view on how to resolve the puzzles that we had. We've always had puzzle; the history of science is the history of solving problems. You might point to the modern epoch, which is Galileo and Newton. That's, let's say, 1600 roughly. They overlap roughly; I think Newton was born within a few years of Galileo's death so it was a continuum.

It was Galileo, I guess, who began the notion of a mathematical explanation for phenomenon. He had these two students on top of the Leaning Tower. The question is the skinny student and the fat student, if we push them both off at the same time which would land first, the heavy student of the light student? So he listened for squishes. If he heard only one squish, they landed simultaneously. Well maybe it was just stones but graduate students sounds better; they're always available. But the notion that these two objects fall at the same speed was totally unexpected.

There's a story. Science, generally and by historians, started a thousand years ago in probably B.C. 1500 or somewhere around there. The Greeks were given credit for asking why things happen and looking for explanations. Then along came, in 400 B.C., Democritus. There was no Republicanus, there was only a Democritus, if you want to make political capital of that. Mr. Democritus first had a model that matter is composed of small objects and space and the small objects move randomly in space. It's a pretty good model for our present atomic theory.

In fact, tomos is the Greek word for cut and atomos is something that you cannot cut. So his notion was if you take a piece of cheese, it's Greek so it's feta cheese, and you cut it in half and you continually cut it, imagining an infinitely sharp knife. He says eventually it will come to a speck of cheese, invisible to your eye because it's so small, but uncuttable and that was called atomos and later became atom. That's because the chemists don't understand Greek they misnamed it and we're stuck with atom.

We know that our atoms can be taken apart so that's the problem. But the notion, that whole imagination of how matter looks. Then he had different kinds of particles that would give rise to the different properties of matter. Occasionally these particles would stick together and eventually you might see the leaf of a flower or a drop of dew on a leaf, something like that would come from an accumulation of these small objects. So that was atomic physics but it didn't go much further than that. It was an idea that was believed then by Galileo and Newton but they had no way of verifying it by experiments. That didn't come about until the late 19th century like the discovery of the electron.

And 15 or so years later, Rutherford discovered the nucleus of the atom and then we had a picture of the atom. Then we didn't understand how the atom worked and there was the same disagreement between scientists about how the atom works and pictures of the atoms. One picture said there's a central positive nucleus with electrons outside, the correct picture. There were other pictures that said no, no it's not that way; the positive charge is on the outside and the negative charge is in the middle. They had different pictures of the atom because everybody was entitled to an opinion until you did experiments.

BINGHAM: So it was business as usual, that's part of your concern now.

LEDERMAN: Right. Now we're in a controversy about a new frontier, totally different frontier. A new frontier, possibly in distance certainly in space and time. Which has to do with this dark energy that is a favorite of Sunday supplements and science magazine articles because it is a great puzzle. And as long as it's a puzzle, there'll be all kinds of theoretical physicists. There are the kind that sleep late; they wander in saying I've been working all night and that's not true, they just sleep late.

BINGHAM: As opposed to the high energy physicists who are sort of bounding around.

LEDERMAN: And take lead bricks and stack them up and do hard physical labor. But it's fun and interesting. They do suggest different ways you can try to cut to the observation. Ultimately, like all of the other problems we've had in science, especially in physics, they get solved by observation and then more speculation about how to make that observation mathematically valid. You put it together and you have to join it to the vast amount of information we have already on gravity and how gravity works. It has something to do with gravity and something to do with the general theory of relativity. Maybe we're going to find some important modification. Whatever it is, it's going to change our world view in a very serious way.

BINGHAM: When lots of these large discoveries are made, statements are often issued. Like Einstein talking about the mind of God or Spinoza's God or Stephen Hawking talking about the mind of God, the theory of everything. George Smoot when assessing the background radiation, talking about the handwriting of God, or you have a book called The God Particle. And then Steven Weinberg sort of complains about all of this and says this is just using the word as an extraction really. It's all about equations. So why do we always reach for this metaphysical spiritual explanation?

LEDERMAN: Well I can't answer for many of the other people. In my case, it was really a device to sell books, commercial. I always worked on that book and I called it the Higgs Particle, it was a working title. The Higgs Particle has plagued us for many years. It was the motivation for building an accelerator in Texas, which eventually was cancelled by Congress. It's one of the driving items in the accelerator nearing completion in Europe right now and to which the U.S., fortunately, is making a strong contribution.

So it was going to be the Higgs Particle but my editor correctly pointed out that no one ever heard of Higgs. How are we going go sell books on a particle that's named after someone they've never heard of? I was bored with the issue. I said okay you name it. He came up with the God Particle. I said wow, all right. I had secretly hoped it would be made into a movie. And the God I referred to in my movie is a woman and I thought Margaret Thatcher would be willing to play that part at the time. Arrogant and tough and knows how to lead, she's very experienced.

BINGHAM: Actually on that point, you have in the God Particle where you're describing Sheldon Glashow's promotion of the fourth quark that he calls charm.

You mentioned one of the authors of the review papers, Mary Gaillard?

LEDERMAN: Yes.

BINGHAM: And then you say in parenthesis, one of the tragically few women in physics.

LEDERMAN: Yes, yes.

BINGHAM: I've been thinking about that. If I think about women physicists-- now this is playing off the Margaret Thatcher thing. I can certainly think of Lisa Randall, I can think of Maria Spiropulu but that's it. It's probably it because those are—

LEDERMAN: [interposing] There's more.

BINGHAM: I'm sure there are but...

LEDERMAN: It's a problem.

BINGHAM: It's still a problem.

LEDERMAN: Oh yes. I think the last number I saw for women PhDs in physics, it's like 20% and that's not enough. Why isn't it 50%? I don't know why it isn't 50%. I think a lot of it is still a cultural problem that young women are not encouraged into science by their parents or by their advisors in school. This is science, you don't want to do science, dear; you're a girl, you want to cook and so on. That cultural handicap is still with us. It should have gone away long ago. Because you're rightly saying some of the women scientists, Lisa Randall, would probably be on everybody's best-ten list of active scientists today. So there's absolutely no logical reason why that's so.

There is a reason. In fact, there was this article someone mentioned yesterday, The Gender Problem. We saw that in our school. I have a school for gifted kids. One of the young ladies walking out of the physics class was overheard by her teacher talking to her friend saying, when I'm in this class I feel like I'm swimming in a pool filled with sharks.

She said it loudly enough for the teacher to hear. Later the teacher called her over and said well what did you mean? I heard you. She said I meant you to hear me. Well what did you mean? She said you ask a question and I'm thinking what does that question have to do with the subject matter you are teaching us. And before I'm even into the reason for you asking the question, six guys have jumped up to give you the answer. They're too fast and that's what makes me feel as if I'm competing with them.

He was interested in this. So he asked permission to teach an all girls class and permission was granted. He taught the all girls. After about three weeks he found that the all girls class was about a week or two behind the mixed class he was also teaching. And he noticed he was teaching differently to the girls class; deeper, slower, more reasoned. This got into the newspapers and got on national television as an interesting gender problem. Then we get a call from the state authorities saying you're not allowed to teach an all girls class, it's illegal. I didn't know it was illegal. I thought it was a stupid rule; why can't we teach an all girls class? Apparently there was a law passed mindlessly to be gender neutral, don't teach an all girls class.

So we gave up on it but I think we had learned something important that was illustrated by the article in *Times*. There is a gender difference in how people learn. There is a gender difference within any particular group on how children learn, how young people learn. We know that the learning process is a very specific process. It's not one size fits all. So I think that once we understand what the differences are deeply then we can do something about it. Either by having gender separate lessons or by having a teaching style that encourages both types of minds, the more contemplative, deeper mind. These guys who want to quickly show that they're superior and jump up and give the answers quickly. There's a problem.

There are a lot of other problems in education that we're learning about in the kind of work that we were talking about yesterday. I think that's something to really be optimistic about - we are learning a lot about how the brain works and how learning should be done. But we're not learning fast enough to overcome the handicaps we have and a chaotic educational system. I'm old enough to look at the national scene on education. I find that there's a lot to be discouraged about, that children are turning off from science when they should be turning on. Carl Sagan was famous to say children are all scientists. Why? Because they ask questions and they come in asking questions.

That's very positive but they get turned off by the time they're in fourth, fifth or sixth grade. Of course there are exceptional teachers who will encourage the asking of questions because that's what a scientist is, he asks questions. Once you ask the question, you've gotten three-quarters of the problem solved. Because now you can go ahead and say ah ha, that's the question. Here's how I will go about answering it.

But the ask the question is the key point in scientific progress and it's the key point in learning things. Kids want to know. And they come into the classroom with amazing misconceptions and fascinating ones. There’s the art of teaching and that's where we also can do so much better. The art of teaching is to seek out these misconceptions. And with the help of the child, try to show the child how these misconceptions are not in accord with how the world works.

BINGHAM: Can you think of an example?

LEDERMAN: Many examples. One example, the teacher will throw shadows on the wall with a sharp light. A point source of light and you get very sharp shadow, and you say, you see kids, light travels in straight lines, it goes in straight lines. The kids say yes and if there's a test what does light do? They'll all write down light travels in straight lines. But it didn't mean a thing to them because to them light doesn't travel. The idea that light travels is crazy; light shines.

Or the teacher might show you that here's hot water and here's cold water. You mix them and hit flows from high temperatures to low temperatures. You have a rock that you heated up and it's hot. There's a cold rock nearby and eventually they'll come to thermal equilibriums. Heat flows from hot to cold. Again, heat feels it doesn't flow. The notion that heat flows is a notion that the teacher got from classes but the children don't have that notion.

So there are these examples of misconceptions and it's a glorious exercise in good education to root them out. Unless you root them out, they'll stay there and grow right through high school and college.

BINGHAM: Somebody pointed out at the meeting yesterday that it can take at least ten years for research and current journals to actually make its way into textbooks.

LEDERMAN: I would think ten is very optimistic. My guess is it's more like 30 years or so, but okay.

BINGHAM: So essentially kids are learning things that are 30 years out of date?

LEDERMAN: It's much worse than that. You've touched on the whole problem. Our curriculum, this nation's curriculum in high schools is about 100 years- well, it was carved out 100 years ago in a famous committee. A national commission appointed by the President, chaired by the president of Harvard. Of course, who else would do that?

And they came up with a sequence in which students take biology first. After biology they take chemistry and after chemistry they take physics. It's perfectly okay in 1900, perfectly okay in 1920 - totally wrong today. It's just backwards. It's wrong because we learned in the 20th century a lot about chemistry, a lot about physics. Talked a little bit about the quantum theory. We understand so much more now than we did then and that curriculum is just backwards.

So if you open up your child's ninth grade biology book and still 98% of all high schools teach biology in ninth grade. And it's full of long Latin words that are memorized. I remember my grandson, he memorized. In the first ten pages I had 20 or 30 words that I had no idea what they meant, a lot of syllables. But my grandson, he knew what they meant. But he said as soon as I pass the test I'll forget these words because that's what happened last week. That's not science.

The only subject that really gives not only a knowledge of how the world works to students but gives a knowledge of how science works to students. That's if you do the simple things. You throw a ball up in the air and it comes down. Why does it come down? A car. Newton taught us that in order to have a change of motion you have to have a force. There's a car at rest and somehow noise and the car goes off. What force acted on the car? It's a nice question to ask mom and dad and so on. You'll get answers, the motor. But the motor's inside the car so it can't really push on the car. What's pushing on the car? A lot of answers come in. Finally somebody says well the only thing that's pushing on the car is the road. That's the only thing touching the car from the outside is the road. In fact, if the road is full of ice and icy, the car won't go. The wheels will turn and the car will stand still so the road must be very important.

This kind of thinking is what starts you off in physics and gives you a feeling for how science works. You take Newton's equation, a simple equation and wonder what problems are. Algebra I should be a seventh or eighth grade course and it isn't. In most schools it's a ninth grade course. So you're taking math and you're taking physics simultaneously. That's okay if the teachers can talk to each other.

You have another problem. Teachers don't have time to talk to each other. Now when I'm elected President I expect to run not this time but next time. I'm going to make sure that teachers have maybe 20% of their time free to talk to other teachers as part of their job. That'll be expensive; add 20% to the total salary of all education. I don't know if it's two weeks or three weeks in Iraq. But I think it's eminently affordable to give teachers more time to become better teachers.

In Asia, teachers are given a huge amount of time to be better teachers. Collegially they talk to each other. Then if there's something new in the newspapers, they'll call in a university guy to say what's this dark energy. The kids are excited by it; I want to be able to explain whatever it is we can explain. Anyway, we're beating on this problem.

We've got a lot to do in this country. There are a lot of efforts. You know very much here in your organization, you're very concerned about fixing education. But fixing it is a very huge job because we have this terrible system where you have 50 states when I last counted. We have 15,000 school districts, each with a superintendent. We have legislators who vote the money for the schools. We have teachers and teachers' unions that restrict your total freedom to do things. There are positive aspects to all of these things. You have schools that train teachers. Are they doing a good job?

I'll tell you for sure that in primary school teachers come out of the schools ignorant in math and science. They want to be good teachers; they'd love to be good teachers. They were never asked to learn enough math and science to take these young scientists who are coming in full of questions and blow on that flame and get it into a roaring inferno. That's what good teachers would do and teachers need to be trained to do that. So we have a big problem in schools everywhere you look.

Right now my biggest anger is with the universities because universities are not doing a good job. They do not continue the inspiration that kids getting out of high school have about science. The student that are getting out of high school who say I'm a science major. I love chemistry; I love biology. Then they go to college and 50% of those kids change fields into non-science fields. That's the statistical data. Why? Because they go into a class of 200 kids and they see a small professor somewhere down there. Or maybe a teaching assistant who's English is not so good. The blame is on the universities, depersonalized.

Kids in high school, at least there are 20 or 30 rooms in class. These lecture rooms for Physics I or Chemistry I, they're huge. I think it's UCLA at least at one point had an auditorium with 400 kids, all there sitting there listening to this one professor. You can hardly see him without binoculars. Oh, there he is down there.

BINGHAM: Didn't they try this notion of physics first in this area, in the San Diego area? What happened?

LEDERMAN: I've been working on this for ten years. Probably we have somewhere between 1,000 and 2,000 high schools who have changed their sequence from biology first to physics first. I get emails every week from a school that's on the verge of doing this, has done this. Wants advice, and so on, on how to do this, wants more details on what's on the physics curriculum. Here in San Diego it's a really sad story because they had some very good science teachers, leader of the science department and a very good board. They decided they would install physics first. I don't know.

Four or five years ago, maybe six years ago 9,000 kids registered for physics in ninth grade. And they did a lot of preparation. They trained the biology teachers, they trained physical science teachers, middle school teachers to teach conceptual physics in ninth grade. Conceptual physics means it concentrates on concepts rather than mathematics, although you bring the mathematics in gently to prepare the students. Ultimately you really have to do it mathematically but you don't have to do that now. You can grasp concepts now.

Apparently there were a lot of problems. But after two or three years of stumbling and teacher experiencing increasing and so on, it began to work successfully. But by then, parents had organized, I think as I understand it, in two groups. One group said you're watering down the physics. You shouldn't teach physics without mathematics. You got to have physics, you got to have calculus and so on, which is not true. Physics is a conceptual subject and it's concepts that you have to grasp. The mathematics is an enormous convenience and probably essentially if you're doing research. But these kids are not doing research. They're beginning to investigate how we understand the world.

Another set of parents said the physics is too hard. Junior doesn't have that grasp, which reminds me of the story. Willie it's time to go to school, get up. No. What do you mean no? I'm not going to school. Willie you got to go school. Come on, you'll be late. I don't want to go to school. Why not? The kids hate me, the teachers hate me, I don't want to go to school. Willie I have two reasons why you have to go to school. You're 40 years old and you're the principal. Is that relevant? No. I don't know. Gets you on a different subject.

BINGHAM: A lot of the talk yesterday was in fact about disparities and the different constituencies in this huge education program.

LEDERMAN: That's right. No country has the burden we have. Another interesting story is I worked a lot in Chicago with primary school teachers. We organized to teach the primary school teachers how to teach science to children.

We stole a lot of the material from the Lawrence Hall of Science. It was beautiful material, right out of Piaget's advice for how children learn, how anybody learns. It's beautiful materials in which the kids do experiments. The teacher has this inquiry method of not asking the question and immediately giving the answer. Extorting the answer from children's thinking.

And that's what you have to do in elementary school and the teachers aren't trained. So we decided to train teachers. We investigated this. With experience it took us two and a half years of getting 80 hours somehow out of the teachers because these were working teachers. We got them in the evenings, we got substitutes, different ways of teaching these teachers. And it started to work.

A friend of mine from Paris came to visit and I took him to some of our schools. He watched the procedure. The furniture is different; they don't sit in rigid stools and benches but they are around the table. There's a kid with a stopwatch and they're counting soap bubbles and measuring things. He was just blown over, that's call vou ver se in French.

He went back to France and talked to one gentleman called the Minister of Education. Within a year, training of teachers in this kind of teaching was in 800 schools in France. They gave it a name La Mana La Pot [phonetic]. I have a book somewhere that translated it into English. Beautiful things and it's spreading over Europe like ooblech [phonetic]. It's a contagious, wonderful way of teaching children how to think scientifically. So that's the advantage.

Here we have the Chicago Public Schools and if one superintendent is encouraging but he goes off to a different job. Someone else comes in and may blow the whole program. In teaching and spreading the notion that physics ought to be the first step, we've had over and over again examples of unthinking superintendents.

Most superintendents are not scientists. They don't understand science. And they decided that all the kids in this school are going to have to take a crucial exam in tenth grade and that would be biology. Well that kills physics in ninth grade. You can't do it. So you have this complicated problem of diversity of disconnecting in the 50 states. A poor teacher who is used to the methods in Alabama and moves to Minnesota, it's like a foreign country.

I think we have to inject coherence into the system. And that's, in some sense, an opposition into our founding fathers who said education is a local responsibility. Well at some point, I think education is the future of the nation and therefore it has to be a national responsibility. In my opinion, we're going to have to make some kind of change. The benefits of the local control are very strong. It's a variety of things but the communication between states has to be improved. You've got to preserve the states' authorities. But there are methods, I think, whereby the states can start talking to each other. Anyway, that's one of our problems.

BINGHAM: Let's just look at some of these other issues that came up. In terms of the teaching of science, often what's needed is a really great teacher. So of the physicists you've known, for example, who are the great characters? Fermilab is named after Enrico Fermi.

LEDERMAN: Enrico Fermi, tremendous person. I knew him and met him. He was someone, a wonderful guy to talk to because he was so perceptive. Richard Feynman is another great man to talk to. The knack of Mr. Feynman was you couldn't ask him a stupid question. No way because he would listen to the question and he would reword it by interchanging two words here and two words there. And suddenly it was different question. He'd scratch his head and say Leon, that's a good question. I never thought of that. You walk away from probably one of the most outstanding scientists of our times. He praised you, you're dancing on air. You're wonderful. He was a human being and a great physicist and a wonderful one to talk to.

My own mentor at Columbia was I.I. Rabi. It's interesting that Rabi, who got his PhD in Europe and then settled at Columbia University and J.R. Oppenheimer, the gentleman who was in charge of the nuclear bomb at Los Alamos. He went to Europe and got his PhD and settled on the west coast. These two guys founded schools, which spread good science teachers all over the nation. And made it possible for the U.S. to be hospitable to the influx of refugees during and after World War II. So these were guys who did tremendous things.

Rabi was a man filled with wisdom. He was very wise. He also advised us; I thought he was sort of nuts. These are all corridor discussions. He'd sit on the floor, lean against the wall and tell us what life is like. He said after you've done a few experiments I advise you to go to law school, get a law degree and run for office. Rabi was an advisor to Eisenhower. Eisenhower had been Columbia University president and took Rabi to Washington very often. Eventually started, after Sputnik, the Science Advisory situation in the White House. And Rabi was important in all of that. He knew all about advising leaders. But he said the power is in being elected.

So he urged us to run for office. I must say there's a scientist, a physicist at Fermilab who is running for Congress in a Republican area as a Democrat because he was inspired by that idea that we have to be elected. You have a Congress that's 97% lawyers or some number like that; that's dangerous. You want a mixture of professions and experience in the Congress so you can have wisdom on many, many different things.

BINGHAM: Two question there. We'll talk about the science debate and the whole notion of scientific literacy and spreading of science throughout the political arena. But one of the questions I tend to ask people is, who is the wisest person you know? Who is the smartest person you knew and what's the difference?

LEDERMAN: There's a difference. I don't know if I can articulate it. But I would quickly pick Rabi. He died at the age of 90 probably ten years ago. But he had a vision of the world, which he shared with his students, that was profound. He had a vision of science as sort of the saving grace. He was worried about many things in modernization. And he was concerned about education in a deep way. One of his wise things was this notion that we need a distributed sense of knowledge of how science works. He was very worried about science literacy. Rabi was also worried about a student body that was very capable.

The Physics Department at Columbia was awesome. There were five or six Nobel winners. Charles Townsend invented the laser; he was in Columbia. Willis Lamb, another Nobel Prize winner for measuring something which is in the literature called the Lamb Shift. Rabi himself is Japanese, Yukawa was at Columbia at the time, the first Japanese Nobel laureate and so on. He built this department.

One of his wise things was that when a person applies to this department as a graduate student, he wouldn't worry about the college record. He says, look, the kid's in college, they're disturbed, their hormones are raging. They are doing many things. You got to give them another shot. Let this department be very loose. Warn them that they are going to have to work hard. And after two years of course taking there will be a crucial exam. Warn them that this is not easy but let them have a shot at it. So a lot of students came to Columbia that would have never gotten in to Princeton, Yale or Harvard because of their high standards. Every time there would be somebody who was a winner, a profound guy. A guy that changes the way we do physics, that's wisdom in many ways.

He also visualized Europe after the war as needing a big laboratory so that all the European countries could collaborate. He was one of the founding movers in the formation of something called CERN, the European research laboratory on the Swiss-French border where the big machine is now going. He was the push of that. He said U.S. ought to help Europe by forming this organization that would compete with us. Otherwise we'll wipe them out. But if all the European countries get together and lick their World War II wounds and that's what happened. So now CERN is one of the great laboratories in the world and they're competing with us. We love to hate them. It's much better to ski in CERN than it is to ski in Illinois, I'll tell you that. I don't know if you can ski in Illinois.

BINGHAM: And the smartest?

LEDERMAN: The smartest, that's easy. That's Richard Garwin. Richard Garwin is a physicist who--

BINGHAM: [interposing] Didn't he work on Star Wars?

LEDERMAN: Yeah. He was involved with that. He graduated from the University of Chicago. He was a Fermi student and Fermi often said Richard Garwin was the smartest student he ever had. And Fermi had a lot of smart students.

BINGHAM: Sorry to interrupt. But wasn't there also this one line joke that people used to say in response to the idea that democracy. Meaning everybody gets the same vote like Fermi. Do you remember that joke?

LEDERMAN: Was it good?

BINGHAM: It was supposed to be.

LEDERMAN: Then come on.

BINGHAM: Well obviously not this time. It was supposed to be. The people were all sort of basically saying how could you possibly have a democracy when you'd be reducing someone's intelligence like Fermi just to one vote like the rest of the people.

LEDERMAN: I think, yeah.

BINGHAM: So Garwin.

LEDERMAN: Garwin went to work for IBM and I think in a short time he was irreplaceable. I remember once the CEO of IBM was looking for Garwin. He called him up and his secretary said he's out of town. Well where is he? I don't know. He didn't let me know. You think the CEO would be a little irritated. Instead a very polite note was sent around to all the scientists saying, please when you're leaving town let your secretaries know where you are just in case you're needed. So Garwin organized a protest against this restriction on his freedom. It was pretty amazing. But anyway Garwin is a guy who solves many problems.

In the beginning he spent a lot of time in the arms business, consulting with the Pentagon. And was probably one of the guys who contributed strongly to the success of Teller's hydrogen bomb. He was very gung ho to make sure we would not be threatened by the Soviets and so on. But little by little he got worried about that. And eventually got more interested in disarmament and he became very active in trying to control nuclear weapons. Again, always with cogent advice he single handedly probably protected all of us against atmospheric disaster with the-- what was it called, the airplane that flew faster than the speed of sound?

BINGHAM: The concord? The SST?

LEDERMAN: The SST, that's right. He argued cogently that it's noise level, its exhaust gasses that if we had the number of SSTs that we now have in the number of standard 747s and things like that. The atmosphere would be unbreathable. He's very logical. He's done a lot of wonderful- and he's very smart. He loves to solve other people's problems; he will drop anything. If somebody calls him up and said Dick we have a problem here. He'll say lock the door, I'll be right there. And goes and solves people's problems.

He just has a repository of a command of knowledge.

We worked together on someone's experiment, which took 36 hours, and a major discovery we made. The whole experiment took 36 hours. Probably if not for Garwin, it would have taken maybe 36 days. But he had some ideas on how to make the experiment very quickly. It was one of these things where I drove from Columbia to the laboratory that was 20 miles north of the city. And Garwin had not been in the city. When he called me I said come over, I have an idea about an experiment, because one of our colleagues, Madam Wu, a Chinese American lady, has some results. So he came over that evening, it was Friday evening. We talked about it. There was a graduate student there puttering around with some of his thesis experiments. And we said that's just the experiment we need. So we took apart the student's experiment, the student started crying. We said don't cry, everything will be all right.

Then in a day and a half we had a new experiment set up. We found that a long held notion, get this now, of mirror symmetry, was not a correct theory. For years, 50 years maybe, people said if you have a lot of experiments in this room and one wall is a mirror. You take a videotape and you photograph either the real world or the mirror world, could you possibly tell the difference? All the physicists would say you can't tell the difference. The mirror world is a perfectly feasible real world. In our experiment, we found a particle, which whose mirror image doesn't exist. There are ideas in which the muscles of the brain haven't been used along those lines.

BINGHAM: But the joy of science obviously for you is powerful. But if you couldn't have been a scientist what else would you have done instead?

LEDERMAN: Well a concert pianist.

BINGHAM: A concert pianist?

LEDERMAN: I like that idea. What else? I think realistically--

BINGHAM: [interposing] You like music?

LEDERMAN: I love music but I can't play. My fingers don't do what I want them to do. I think actually, to be more serious, I would be a teacher. I am a teacher.

BINGHAM: You are a teacher.

LEDERMAN: But I would be a full time primary school teacher. I think I would like to do that.

BINGHAM: You're probably going to get some offers.

LEDERMAN: Well, yeah. But I just watch a good teacher with children and it's just a pleasure to see that. And when I see this, there's a little bit of that. There's a little bit even when I teach undergraduates or in the high school I started it. When you've done something right, you're surrounded at the end of the lecture by students who keep asking questions. You've stirred them and now they have questions. That give and take after the lecture is just wonderful.

BINGHAM: What are the most important mistakes you've made? And what did you learn from them? What would you do differently?

LEDERMAN: There's one experiment, it's eventually was something called the discovery of the charmed quark. You could say it trippingly from the tongue, the discovery of the charmed quark.

BINGHAM: The Glashow thing we were talking about.

LEDERMAN: Yeah. It was the Glashow thing, but we were after a quark. I missed it, not only once, not only twice, but three times in three different accelerators. I first tried the experiment in the large Brookhaven accelerator. That was in 1968. And we had a lot of data but the apparatus- It was sort of like looking for a star using instead of the nice lens you were using a Coca Cola bottle. So the optics was not very good. Our apparatus was crude in the interest of speed and we missed the particles right in our data but hidden by background garbage junk.

Then we tried it again in an experiment in Europe because I wanted to use the European machine at CERN. It's a beautiful place. On the weekends there's nothing to do but go skiing and good food, all advantages of being in Europe. They had an interesting machine and we were able to get on that machine and we tried a different approach to look for this charmed thing and we missed it. Didn't see it, yet it was there. Then Fermilab came on the air, it started its experimenting program in 1972.

BINGHAM: Were other people looking for this thing at the same time as you?

LEDERMAN: We were in the lead in a sense. In '72, by this time people were getting more and more interested in the experiment. Again, at the new Fermilab machine, for complicated reasons our apparatus was not able to find this particle. Two years later, Mr. Samuel C.C. Ting led a group back at Brookhaven with more modern apparatus, more modern detectors in the facility. And he found the particle. Then a good friend of mine at Stanford almost simultaneously--

BINGHAM: [interposing] Burt Richter.

LEDERMAN: Burt Richter found that same particle so there was a joint. They fought each other because they were within hours of which one was first so they shared the discovery. Went back and looked at the data and back at the original Brookhaven experiment, a little shoulder in the apparatus that we argued about. Is that a particle or is that just some background? That was interesting that I missed it three times. Nobody can hold up experiences that stupid.

BINGHAM: What was the last book you read for pleasure, out of curiosity?

LEDERMAN: Book I read for pleasure.

BINGHAM: What types of books do you read?

LEDERMAN: They are usually detective story books. Who is our famous detective story writer?

BINGHAM: You'd be surprised how often that is the answer from scientists, by the way.

LEDERMAN: It's hard. I read sometimes on airplanes. But usually on airplanes I'm worried about being interviewed. I have to prepare and know everything or something else like that. But I like good well written detective stories. They're great but some are better than others. Who is the guy that writes mostly books about lawyers and juries and stuff like that?

BINGHAM: John Grisham.

LEDERMAN: Grisham. I like him. In fact, I met him and he was a very charming guy. Whoever introduced him to a group of us said he's the runner up to Shakespeare. He lambasted the guy and said Shakespeare, what are you talking about? I just tell stories. You like my books, you like the stories. You put them down, you forget about them until my next book comes out. He had no pretensions that he was a great writer. He certainly was a good storyteller. He is a good storyteller.

BINGHAM: Still quick thought about this science debate 2008 because that's a fairly large group gathering momentum now who are arguing for there to be a science debate. Whether it happens or not, it's still a huge number of people are now pushing for what could be a very powerful science literacy movement as well at the same time.

LEDERMAN: About 60,000 scientists have signed the petition to all candidates, I guess there are three now, to participate in this debate. We're not getting encouraged by the principals. I'm sympathetic to candidates who are asked to debate science. They are not scientists, they don't know science and they do what you hope they would do when any of them are elected President. They surround them self with good advisors. The more they knew about science from the backgrounds, which is not much, but some of them may be more in to trying to educate themselves in science than others. The idea of campaigning for them to be interested in science is the issue really. Because it is our belief as a scientific community that never- I go way back to pre-Civil War times as you can notice.

BINGHAM: Back to the beginning of the universe.

LEDERMAN: The beginning, I was there, I was a terrible noise. But there has never been a more important time for science to occupy the leadership of nations. I say that being aware that maybe this has been said before. We are definitely in a period of tremendous uncertainty. I can make a list of all the issues that will face the next President. If you look at them, the first on my list is global climate change. I'm very alarmed by the data and the events that are supporting the estimation. Even showing that the estimations are way too conservative that the world is in for a major change due to warming. If we don't take precautions very soon, there will be a tipping point. And there will be awesome possibilities of sea level risings and so on. I accept these things as very distinct possibilities. That implies many things.

People are hoping that somehow solar energy and geo-thermal energy and all these many, many different possibilities. All of which will help and ease the transition because along with global climate change there is energy, sources of energy. What are the sources of energy? We keep using coal or we're using it. The sequestering doesn't quite work as well as we hoped it might work. Then there's an issue of what energy sources you need. Again, a scientific challenge if you like to do that. I think we're going to have a have a change in lifestyle. That's my reading of the experts.

The general many climate people and energy experts and so on have looked at all these things. Oil will show up and be helpful at the level of 5% or 3% or 10% or 12%. But ultimately we cannot have the kind of automobile society that we have now. The automobile encouraged suburbs and shopping centers all over the place. That's not going to be feasible and we need substitutes for that and a change of lifestyle. That tells you again that we've got to have a public that's comfortable with these scientific issues so they're not bowled over with nonsense statements. There are lots of people who will site absurd objections to what's going on.

Well, climate change happens every thousand years, that's been looked in to in great detail by these experts. They go back 10,000 years and there's nothing like what we have now. Tracking the energy, the temperature of the atmosphere and the amount of carbon in the atmosphere. It tracks identically, nothing like that has never happened. We never had this large increase in temperature changes in more than 10,000 or so years. So anyway, these are serious problems and I think everything points to many, many issues that have to do with science.

Almost anything you look at that's coming up before Congress, immigration. Yes even the deficit, national defense issues, clearly terrorism is a very important issue that we have to pay attention to. All of these things have science sides and if we don't have a public that takes part in this, you're giving up democracy. This is a democratic society and people should know about it.

I bet you anything if you take a poll somewhere in the audience. You say how many nuclear weapons do you think we have on alert. They will say why do we have nuclear weapons on alert? Who are we aiming them at? The Russians. Well the Cold War was over 15, 20 years ago, why are we aiming weapons at them? Are they aiming weapons at us? Well if we're aiming at them they are probably aiming at us. Why? Who justifies that?

I think we need to have a public that's interested in these issues and that asks these questions. So you start with kindergarten and you do better. But a public understanding of science is something that has to go right away. And go at all levels from pre K through the grown ups, the parents, the citizens that have to make decisions and go along. They can ask their government why are we doing these things. I call it the Oprah Winfrey fantasy. If we can get Oprah interested in science, boy, we can really be ahead. She doesn't answer my telephone call.

BINGHAM: She probably thinks you're the other Letterman.

LEDERMAN: Yeah, maybe.

BINGHAM: Just a bit of a tease. What are you optimistic about?

LEDERMAN: I think yesterday was a good day to be here because I was optimistic about the scientists, the neuro guys, the neuroscientists talking about their progress in understanding how the brain works. Supplemented by the cognitive psychologists who were also in that goal, that phase. And of course you have a large number of neuroscientists who are applied neuroscientists, which are teachers. They're applying their notion of children's behavior.

If the communication can be improved so that people in Maine know what the people in California is doing. There's communication among the teachers and the educators and the scientists, that's beginning to happen. It's still uncoordinated but we have a messy system. We've got to somehow install some national strategy and superimpose that on a system, which has only varied components. I think I'm optimistic that we can organize ourselves to make a better educational system. We must, we have to. That necessity, I think, will be satisfied. We need coherence. We need a new election that we'll get. And I'm very confident that we have a good chance of organizing ourselves to do a lot better in the education system.

I'm very happy with what's going on in China and India. People say we can't compete with them. I would rather cross out the word compete and say collaborate. We can collaborate with them and that's important. Competition and collaboration are often very similar. We have this laboratory in Geneva, we compete with them but we also collaborate with them. You can do both. In order to collaborate with them we have to know enough science to read the papers they write. Understand them and show them what we're doing along those lines. But some little kid in China is going to work on a cure for senility in a hurry. I want that. I think the fact that good science is going to pour out of China and out of India are very good things for us, good customers. Progress in understanding the world we live in. Maybe alleviating disease and poverty and the other things we have to do.

BINGHAM: You're talking now about aging, so on and so forth. Let me go back to that question I did earlier about the God thing. Is there anything else out there or is it just quarks?

LEDERMAN: I'm a scientist. If there's anything out there that we don't know about- I'm not a believer but if there were data that indicated that are events which are counter to the laws of physics as we know them. That would be a very impressive discovery but over the thousand years of recorded sort of reasonably good observations nothing like that has ever shown up yet.

BINGHAM: We'll close on this but there are still these issues that keep coming up in physics, the Bell’s Inequality. John Stewart Bell, issues that David Bohm has talked about, about nonlocality and so on that seem to leave open the sense that the standard model doesn't seem to fully answer. Do those things still give you pause?

LEDERMAN: The quantum theory is not an easy thing to grasp. Richard Feynman had an easy way of teaching the quantum theory. And the way he did it got him into trouble with women drivers. A policeman stops a woman driver. What's wrong officer? He said you were speeding. Oh no, I wasn't speeding. Yes. I clocked you at 60 miles an hour. Ah ha, she says, that's crazy I've only been driving 20 minutes. Well I'll explain it to you later but in a sense that's the quantum theory.

The quantum theory is somebody said, some famous physicist, nobody understands the quantum theory. It works. It works in an enormous way. Everything you know about cell phones and computers, an incredible number of things that we now know on the atomic and sub-atomic and nuclear level are governed my the quantum theory.

Einstein himself was opposed to the quantum theory. But he gave up on arguing that it's incorrect. He decided that it is a correct theory. But he decided then that it was not the final word because he didn't like the idea of probability. If you're walking on Michigan Avenue in Chicago and you see yourself in the store window. You see a guy in the window dressing a mannequin, ha ha. And you see yourself and you say not too bad. Now how did that happen?

The sun has photons. Einstein got the Nobel Prize for the photoelectric effect, that light produces electrons when it hits the surface. So the sun's photons hit your face and they're reflected from your face to the window. Some of them go through the window because the guy dressing the mannequin sees you. So he sees those photons. But some of those photons are reflected from the window and come back to you when you see yourself. What decides whether a photon will go through the window or come back? The answer is it's totally probabilistic.

Einstein always talked about der Alte, the Old Man. He talked about God but only as, I think, a substitute for nature. Nature is such that the probability is 8% that the photon will come back and 92% that it will go through the window. That's all nature can tell you about is a probability and Einstein hated that notion, that he couldn't make an exact calculation. But it turns out over and over again; experiments bore out the notion that quantum mechanics is a spooky theory. And doesn't behave in accordance with the good old Newtonian world in which things happen according to some law of physics.

You have to put in this probabilistic factor and when you do, you get the right answers. You can build cell phones, computers, giant computers. All the microelectronics we have today comes out of that understanding. There are people that don't like the formulation or are hoping they can make a better formulation. I give them all the encouragement. But so far to use the quantum theory as a physicist, it's there, it's useable. And you're only worried about a conceptual problem that gave Einstein a lot of trouble and people who respect Einstein have followed him in looking for a sharper way of talking about the quantum theory than we have.

But what's more interesting are the frontiers now opened up by astrophysics. Those guys are going to really change our world view. When I was the director of Fermilab, I hired a bunch of astrophysicists to come and live at Fermilab like Rocky Kolb, David Schramm and Michael Turner. These were outstanding astrophysicists and we built a good astrophysics group. Now what does an astrophysics group got to do with a laboratory that's devoted to the smallest things, the quarks and electrons that are inside the nuclei of atoms. Well it turns out there's a deep connection.

The big bang theory says in the beginning everything was particles. So there were these incredible number of particles whizzing around, smashing into each other, separating. Eventually as it expanded and cooled, it came to be a sort of sticking together. Out of that came protons and neutrons and eventually nuclei. Then along came an electron and made an atom, now we can employ chemists. They had something to do because we made atoms. Chemistry is the subject of atomic reactions.

We have a huge knowledge, useful and also aesthetic if you like, picture of how the world works. And all of a sudden these astronomers come out and they say, you know this expanding universe is speeding up its expansion. Well that's a blow; it was totally unexpected. That's called dark energy. We gave it a name so we have something to talk about but we don't know what it is. What is the mechanism by which these galaxies, each galaxy has billions of suns. Suns may have I don't know how many planets per son and they are all going away.

They are speeding up; something is pushing them. We don't know what it is. So that's a mystery at the frontier of our knowledge. That's very exciting. Somebody, maybe a little kid in a village in China or India, but hopefully maybe somebody in San Diego or New York some place, will find a clue to this great puzzle. But the fact that we have a puzzle is very good. We don't understand it.

BINGHAM: Leon Lederman. Thanks very much.