Mark Royce:	00:00	So, as I've researched your history, it's quite impressive. I've learned that you've done a lot more than just the modeling. Your career has been focused on many, many areas of development in the sciences.
Dr. Hestenes:	00:13	Well, my undergraduate degree was speech and philosophy. That's right. Then I decided that you had to have something to speak and philosophize about. And so I changed my major to physics the last semester of my senior year.
Mark Royce:	00:33	See, now, I didn't see that in my research.
Dr. Hestenes:	00:39	I went to UCLA. And my father was chair of the math department at UCLA at the time. After my sophomore year, I moved to Pacific Lutheran University. The main reason for picking that particular place was that my uncle was president of Tacoma, Washington. And so I finished there. I was married in my senior year. So, having decided that I had to go to graduate school, I had to find some way to finance that. And the Korean War was just winding down. And so I volunteered for the draft and I was inducted in Hawaii because my wife was born and raised in Hawaii. And so I spent then two years in the army during the Korean War. And then I went back to summer school in 1956 at UCLA and that's where, that's when I started making up my background in physics. I'd already had a bachelor's degree, so I didn't need to satisfy any of the requirements for a physics degree. So that meant I could take graduate physics courses. It turns out that I had the best advisor that you could possibly have. Well, there's a long story about this. I've just written a history about my father because what was happening there is my father, during World War II, he was a mathematician. He was in charge of organizing work of mathematicians throughout the United States. The first electronic computer in the western United States. Actually the first functioning, what they call a Turing computer these days, was produced right there while my father was in charge. And so, I was involved in the foundation of computer science right there. I've just written a short history for a historian of mathematics. They contacted me because of the interest in my work. His work, during my life, was classified for a lot of the time. So therefore, I got some unique insights. but I didn't appreciate the insights until I was a professor myself, many years (later). That's when I really understood what he was doing. Before that he was just dad.
Mark Royce:	03:20	Yeah. You know, it's really interesting to me that by at the young age of 23 years old, you began a passion or you

discovered within you and interest in, uh, educational approaches. You know, teaching.

Dr. Hestenes:	03:35	My major was in speech, right? So I was interested in communication, and I was interested in the philosophy of language, but actually not specifically in teaching. When I started getting more directed to teaching was after I had, was hired at Arizona State University in 1966, and Arizona State University had just become a university about I think, 1958 or somewhere like that. Within 10 years before. When they had changed from a teaching school to a university, they put the science education department into the physics department. And so we had all the science education teachers involved in the physics department and that gave me a lot of background. This is only, though, 1966, right? So the story associated with the modeling is going to occur, actually 1980. But, so I became a defender of the... You see, there was always competition for faculty lines for education, teaching versus research, and the researchers always won. I was the defender of the teachers, but it was a long story and a continuous battle. Eventually the science education faculty were removed from the College of Liberal Arts to the College of Education. But that was quite some time. They wanted people who did real science and not science education. There was a continual battle. And my father had the same battle as chair of the math department at UCLA, which is the battle between the pure and the applied. Okay. They thought of teaching as applied, but the pure are the people who are doing the real...
Mark Royce:	05:44	Interesting. So there's kind of an elitist approach, or thinking.
Dr. Hestenes:	05:48	Actually all of this competition between the pure and applied mathematics has historical roots that go all the way back into Greece.
Mark Royce:	05:57	Okay. So it's not just about where the money comes from.
Dr. Hestenes:	06:00	No, that's right. Yeah, that's a long story, too.
Mark Royce:	06:05	Okay. So tell me about the early research you did that led you toward the ideas behind modeling.
Dr. Hestenes:	06:14	I wrote an article for the physics teacher, which was published in 1979 and it was called wherefore a science of teaching and that had some remarkable benefits. The first thing about the article was five days after I had submitted the article, I received the page proofs. This is totally unusual, you know, because in

mathematics you may not be accepted for a year. Here. I got it before I got the acceptance, I got the page proofs. Wow. And they sent it immediately. In other words, the editor loved it right away. Yeah. Okay. And I talked about some of the foundations in research in psychology, which is the foundations in artificial intelligence. And then that article was read by the head of the part of NSF that deals with science education. And I got a response, unsolicited response. And I was told that my article became required reading for everybody in the directorate in science education. Wow. Um hmm. And then at the same time, in 1980 there was a new student called Ibrahim Halloun. He was applied to Arizona State to get his Phd in physics with a specialty in education. There was no major in education, but he had a grant from a Lebanese University to get this degree. So he, so he came with his own money and the chair, who knew I had, uh, done something with education. He assigned Ibrahim Halloun for me to direct him with a PhD. He should have consulted with me first. But anyway,

Mark Royce: 08:19 it turned out pretty well. It sounds like.

Dr. Hestenes: 08:21 It turned out extremely well. Um, because after his PhD, he went back to Lebanon and started a graduate program in science education while the war was going on between the Christians and the Muslims. So this guy had real motivation. Now he passed the graduate examinations that qualify you almost immediately. So we moved very fast because he was a very smart guy. So I had to assign something for him to work on for his doctorate. The assignment for him to work on was to study the influence of naive beliefs. These are beliefs about physics that people who haven't learned physics. Okay. So rather than naive, maybe it's better to say common sense beliefs. Okay. Because all of us get some sense of how the world works just by interacting things in the world. And so we develop a natural intuition for force, for example, like the force be with you.

Dr. Hestenes: 09:36 Yeah. Yeah. Okay. And which actually is a misconception. And so I wanted him to work on a proposal, developing an instrument to evaluate the effectiveness of physics teaching that is introductory physics teaching at the university level. So we developed an instrument which compares common sense beliefs from scientific beliefs. It's a multiple choice test that you have five alternatives. Okay. One of them is a statement that is a physics statement and the other are common sense statements. That's okay. For example, what idea, which goes all the way back to Aristotle, which is the idea that if something is moving, there must be a force that moves it. Okay. We see

		objects around us and then we move them, we push them. And so we have to exert a force on them. So they have, so they have a sense, so the generalization that people come up to can be characterized as motion implies force.
Dr. Hestenes:	10:55	If something moves, there's a mover. Okay. And that was a proposition formulated by Aristotle, however it's wrong. So, so we wanted to systematically survey students' understanding of motion and its causes. So we created a test and this got started with Halloun during 1980 to 84 okay. During that period, that's when in '84 he finished his PhD.
Mark Royce:	11:27	who came up with the term force concept inventory.
Dr. Hestenes:	11:31	Uh, that can't, that's mine.
Mark Royce:	11:33	Okay.
Dr. Hestenes:	11:33	But the force concept inventory was published after 1990, I think it was 1992 I don't remember the actual date that it came out, but we kept improving it. And, and so we designed this instrument and let's, let's call it a test. About your understanding of motion and its causes. So the first version of that was published around 1984 this test then was applied to the students that take introductory physics before and after when they started the course, the students were given this test to see what they understood about physics.
Dr. Hestenes:	12:16	And then we gave it post-test after the course is over. So the, the object is to see their initial beliefs. How those were changed by instruction. So there were about a thousand students, there were four lecture courses with four different professors teaching in four different ways and the results were totally amazing. These are among the most amazing results in the history of physics education. Can you give me a capsulated description of what those results were? Yup. So here we had four professors with four different ways of teaching. Okay. One was a problem solver. He would just work for problems. Drill instructor. Another teacher gave the lecture demonstrations about physics phenomena to develop their intuition. Another professor thought that what's important is to understand the logical structure that connects everything up, the conservation laws of energy and momentum. And the fourth guy was just teaching for the first time and all he did was just follow directly the textbook, so the first result is that their scores were poor.

Dr. Hestenes:	13:38	There's an evaluation level of this test, which I call the Newtonian threshold, which is if you have a score below 60% then your understanding of the [inaudible] laws of motion were inadequate for reasoning correctly. It's almost useless at that level. That's a 60% level. Whereas the students that had had high school physics were, I think it was 48% the average. Now it turns out that that was almost the same average for all of the students that started the course. Then we got the post test scores and we could compare the results of instruction for each person and there, the gains were less than 15% they were identical for all the professors within a percent.
Mark Royce:	14:33	Regardless of their teaching style.
Dr. Hestenes:	14:36	Exactly. Now the implication of that is that what the professor did in his lectures and so on has no effect on what the students learned. That's a rather striking isn't it?
Dr. Hestenes:	14:51	Truly is. Yes. And this has been confirmed thousands of applications. So we improve this in the force concept inventory. In other words, the gains that had been for ordinary introductory physics teaching, the gains that students make is just what they would pick up themselves looking at the textbook or whatever informally that it didn't matter what the professor did on the, on the average for, for most people. Right. Okay. So then at about the same time as we were developing this, uh, there was high school physics teacher, Malcolm Wells, and he came and he said that he wanted to do a dissertation on physics teaching and this guy was around 50 years old and he had been high school physics teacher for his whole career and he had virtually all the background that you could ask for and had developed his own ways of doing things. He, he was using the apple computer, programming it for himself.
Dr. Hestenes:	16:00	You see this is, this is in the eighties okay. So that was when you first had, maybe you knew that, remember the little Apple thing, that little tiny window that was in '84 the Macintosh, right, right. The Macintosh. And so Malcolm Wells was using that till he, his PhD was finished in '89 okay. But he first came and talked to me about 1980 and told me that he wanted to do something. He said, I don't need any degree or anything. I just want to do a really good research program in teaching. And so he would come in and we would talk and this went on back and forth. And then in 1984 it would be, I showed Malcolm the results of our mechanics diagnostic test and Malcolm Wells said, oh my students can do better than that -- his high school students. So he was a superior teacher.

Dr. Hestenes: 17:09 He actually was a superior teacher. But it turned out that when he took the mechanics diagnostic with his high school students that he had finished, they didn't do any better. Wow. Yeah. So that started Malcolm Wells (saying) How do you do something that actually has an effect right now? His dissertation, in my estimation, is the most significant educational experiment in science education, certainly in physics education ever done. Hmm. He was able now to change his instruction in a way which actually got much better gains than the physics professors at the university level. But there was another ingredient in that and that is, it's not enough to know that the students have alternative conceptions or if you will, misconceptions about how the world works because they interpret everything in terms of those. The question is how do you get the students to have the scientific view of what's going on in the world rather than the common sense everyday world.

Mark Royce: 18:22 And this is what he postulated in his dissertation.

Dr. Hestenes: 18:25 Well that was his problem. Okay, how to do that. Okay, so the problem had been set by the time Halloun had finished his, his dissertation. But there is another aspect about this and that is how do you structure the subject matter, the physics subject matter and that's where the modeling comes in. Okay. Modeling is concerning the issue of what is science, how does it work? You much often hear about the laws of physics, for example, Conservation of energy as a paradigm. But to use the laws of physics, you have to construct models of the thing that you're applying to. Okay. So my theoretical view is that science is fundamentally about making and using models of the real world. The first published approach on the structure of physics as being organized around models was actually in my graduate mechanics book, which was published right at this time, I think 19, uh, 86 but it was written in 1980 and its final chapter was about modeling. And I wrote during this period articles about modeling and the role of models versus theories in physics and Malcolm Wells then use those two things. The two ingredients to sum up, the students have naive beliefs about motion and its causes. And the problem of instruction is how to formulate the scientific view and the scientific view is understood by a model for what's going on.

Mark Royce: 20:24 So then what you've just shared is the seeds of the development of modeling theory and a methodology for instruction.

Dr. Hestenes:	20:35	Yes, that's right. Yup. Wow. And a, that's still not understood by most anybody except the people who are in the modeling program.
Mark Royce:	20:48	Right. Well that's why we're doing this podcast is to hopefully help more people get introduced to the modeling community and hopefully employing a better methodology in their classrooms.
Dr. Hestenes:	21:00	Yes. Okay. So then how did that happen? Okay, so now I've told you about two key people in the design and the development of a teaching strategy. So by the time Malcolm had finished his thesis, we had a pretty good design for high school physics teaching education with an evaluation instrument. Actually more than one, but the most important one was the force concept inventory, which would give us a way to evaluate how the students' understanding has been improved.
Mark Royce:	21:39	Where are we in the timeline about now?
Dr. Hestenes:	21:42	His PhD finished in 1989 right. Okay. So this whole thing from Halloun starting to Malcolm finishing was about nine years. And in this time I taught introductory physics at the college level and coordinated it with Halloun. But Malcolm had nothing to do with that. Malcolm had his own track because he already had a well-designed curriculum and he had a lot of models that had been developed in workshops supported by the National Science Foundation. Uh, there was a project physics workshop and so on. And Malcolm knew all about all of that. And he had designed a set of very simple experiments for students to learn that would involve the basic models, five basic models. We already had determined what, what those basic models were and what does it mean to have this model. And so the instruction is organized around what we call a modeling cycle, which introduces you to the phenomena.
Dr. Hestenes:	22:53	And the object is to understand what's going on in the phenomena. You ultimately have to have a model which includes, uh, data and results from the experiment. And then the model gives us an explanation. What did you learn from all of this? Right? So we have the modeling cycle. Now, that idea from the modeling cycle goes back in the pre-history through something called the learning cycle in educational psychology. The important precursor for all of this was a physicist named Robert Karplus. That's a whole separate story in the pre history part, which I didn't tell you much about already. Yeah,
Mark Royce:	23:36	yeah. Well we'll stick with this for now.

Dr. Hestenes:	[23:38]	Yeah, sure. Okay. So Malcolm Wells then had a framework and it just about that time we were starting to get, uh, uh, the use of computers in Physics for measuring motion and acceleration and velocity and those kinds of things. Technology was now just beginning. Sure. What now? Now here's the, here's the big thing. After, after, um, Malcolm finished his thesis in 1989, I was so impressed that I contacted the one guy in the National Science Foundation. His name is Raymond Hannapel. So here's another key figure that made all of this stuff happen. I got to know him. I, uh, reviewed a PhD proposal from a young PhD student who got his degree in physics teaching. His name is Jim Minstrell. In the review, there were very critical things at first thought his proposal was rejected. And then as a consequence of the discussion with Hannapel, the program manager, I was with two, uh, professors of psychology on the evaluation team.
Dr. Hestenes:	[24:58]	They were very, very good people. But after listening to what Hannapel had told us, we changed it from one of the worst to the highest. And that guy ended up to be one of the most productive people in physics education research for his career. He's still doing things today. So I remembered Hannapel and when I, uh, saw the results of, uh, Malcolm Wells, his dissertation, I contacted Hannapel and he awarded me a five $50,000 proof of concept grant with no strings. I didn't have to write a proposal or anything. We had to prove it. And that was to run sub workshops in the summer for Malcolm Wells, Malcolm Wells would run these workshops and then, and that, that was a, I think 1991 when that happened. So that was the, the first try to see whether his success could be transferred to other high school physics teachers. That was the, that was the issue.
Dr. Hestenes:	[25:58]	It turns out that it wasn't so easy. I saw, I, I learned, uh, a lot of things about that. Uh, Malcolm Wells, uh, he knew all the physics teachers in Arizona, so he was able to get a good selection of teachers for this summer. And one of the most important things that I learned is that physics professors are incompetent for running workshops for high school physics teachers. And I learned that from my own experience. I banned it. And so we never had any physics professors teaching summer courses. And why is that? Why are professors incompetent for this? Well, for one thing, they don't have the same stake. The professors don't have any stake in what's going on in the physics classrooms as the, as the teachers, the working teachers are. So that's a key thing. And then there isn't as much followup. Anyway, that's just, that's just one minor thing.
Mark Royce:	[27:03]	Well, I think there's a brilliant insight actually.

Dr. Hestenes:	27:09	Yeah, you'd have to look, you have to have some humility because professors are not known for their humility. The crucial thing is that we wanted to inform the profession of teaching. So we want to involve the teachers in training the teachers. And so that's a key thing. So we had these trial workshops, we got a positive result after the second year. And then that enabled me to make a full blown National Science Foundation proposal. So I got a $4 million grant, I think by 1993. Now there's a tragic thing that happened in this day and that, um, uh, Malcolm Wells contracted Lou Gehrig's disease, and he went downhill pretty fast. So I had asked Malcolm to write up his results for an article and, uh, he was too busy working with the teachers. He put all his time in the teachers. So this went on for a couple of years anyway until, so I wrote it up and the force concept inventory is a joint paper, but unfortunately he had not much to do with it because he was severely incapacitated.
Dr. Hestenes:	28:29	Wow. But he had done all the, uh, spade work that was necessary to get the thing going. Yeah. Wow. And then if it turns out that one of the teachers that came in now, in our very first workshop was a chemistry teacher. Oh, okay. Larry Dukerich is the guy. Okay. So that's the next key person. Larry Dukerich, learned the whole thing. And today is one of the world's best workshop leaders. And he did more than that. He developed the connection between the expansion of the program for high school physics to high school chemistry, and he had the benefit of being involved with Malcolm right at the beginning, at the very first workshop. And so he was continually involved in his high school in Mesa, near Arizona State University. So we had easy connection with him for a long period of time. And then we had the a the two big grants, about $4 million and another 4 million, so $8 million or so. And we designed during that period a standard workshop summer workshop that would help these crossover teachers from biology for example, as well as at mathematics and uh, and chemistry to the physics. So Larry was the key person in extending the modeling program from the high school physics into chemistry.
Mark Royce:	30:10	So the grant monies, how did those monies reinforce the efforts? How are those used?
Dr. Hestenes:	30:17	The crucial thing is the design of the summer workshop. Imagine that you have a cross over a teacher and you want to give them enough background so they can teach in the physics class. Some of them haven't even had a first course in physics. Hmm. A college course, although I think certainly most of them, have had one year of physics before. So we learned that we wanted the teachers to be involved in the workshops in a way

that they would be doing it with their students. We found that, first of all the workshops are summer workshops and they are immersion workshops. That is the teachers are together for the entire time. We have learned that the ideal length of these workshops should be three weeks, four weeks is a little better, but three weeks is necessary to really get to it. Unfortunately, we now are having more and more workshops that are less than that. The workshops might work for two weeks, but if there's a week, a follow up during the school year that brings the teachers together.

Mark Royce:	31:30	You know, my wife and Larry are co-teaching a online course based on the summer workshops.
Dr. Hestenes:	31:37	Absolutely. And the, and, uh, online has got to be the big thing. So we had studies on how well the workshops did with their students and, and so on. So there's a whole research program about how the workshops work. Oh, by the way, as soon as I got the first NSF grant, I needed a program manager that would run everything. And, and that Jane Jackson, I was fortunate to get her. Yeah. She had actually been a student of mine in physics. She got her PhD in physics. She provided the connectivity between all the teachers. So there's a modeling Listserv, which I guess your wife knows about that.
Mark Royce:	32:21	My wife has taught for the last 10 or 12 years. Every summer she's taught workshops and she is also expressed the difficulty of trying to do it in two weeks. But the problem is, is the availability of the high school teachers to be free for more than two weeks.
Dr. Hestenes:	32:38	Well, you'll see if we had the right funding. Hmm. First of all, they should be paid.
Mark Royce:	32:44	to attend.
Dr. Hestenes:	32:45	They should be paid at the same rate in which they're teaching. So, yeah, th that we hit, they get some money, but I mean their full salary should be paid while they're attending these workshops. The economics of all of this stuff is a big thing and it's just amazing. The teachers have made up for the deficiencies of funding fantastically. We have well defined evidence that less than three weeks workshops are suboptimal. And if we had the right funding and other associations, other kinds of financial support, I think we could maintain full funding to do it right every time. And that brings us to the main problem to get funding. And my view is having worked with the NSF and the government and so on, that it should not come from the

		government. It should come from the private sector. So I have continued to making some efforts that direction and there's some, there's some hope for it. The biggest development out of all of this thing is the unintended consequence that we have built up a society of modelers. And I didn't deliberately do that, but, um,
Mark Royce:	34:05	Well this is a good time for you to talk about how AMTA came into being.
Dr. Hestenes:	34:10	AMTA.
Mark Royce:	34:11	Yes.
Dr. Hestenes:	34:12	Yes. Okay. So in 2005 the funding for modeling was done, but uh, Colleen Megowan and some other teachers in that last summer decided that they wanted to make things continue.
Mark Royce:	34:30	And when you say the funding was done, you're talking about the $8 million?
Dr. Hestenes:	34:34	No, actually I'd already used that up. Uh, the, the, I got some more funding and, but the, the, the main funding was in the 90s and then it was weaker funding to the end. But, uh, Colleen Megowan and some of the other teachers at that time established their own 501c3 to keep it going. And the workshops have continued funding workshops at about the same rate as we had right until this date. Okay. So that's 2005 to '19. Now, as far as I know, there is no other science education program, maybe any education programs supported by the NSF that kept going after the funding was done. And why is it? It's because it's of, by, and for the teachers, that's what the AMTA is about. So that fits into the remark that I made that professors are incompetent for running these things. You know, usually you, if a professor were running it after the gets of the grant, then he's got other things he has to do and so it stops. The fact that it was anchored among the teachers right from the beginning I think was probably an important factor for it's continuous survival. The survival depends on, first of all, the pedagogy, which is crucial, which is a science that is built around models and modeling. So that's the first thing. So you have a community of likeminded people that have a common understanding of what good science teaching is about and that's what the AMTA has now and its mission now is to cultivate that and keep it going.
Mark Royce:	36:28	You said that was an unintended consequence,

Dr. Hestenes: [36:30]

Unintended consequence. Yes, because I wasn't thinking about trying to make a community of physics education teachers. The community sort of grew up because of the way of the design of the program.

Mark Royce: [36:42]

The other day when we chatted briefly, you mentioned you have some interesting perspectives on the sociology of this modeling community. Can you expand on that a little bit?

Dr. Hestenes: [36:55]

Well, okay, so what is it that is going to make an effective teacher? The trouble with especially physics teachers is that they're not connected to anybody. Usually the physics teacher is the only physics teacher in the school. Only very large schools have more than one physics teacher. Sure. And so they don't have anybody to talk with. We spent some time, Jane Jackson and I, especially in trying to build these local communities of physics teachers to support. Um, but it's very difficult. All the teachers are interested in it, but they can't afford the time like everybody else. Right. We've got things we have to do. So you've got to have a way of connecting up the teachers and that's building up local communities, local groups in schools and so on. And that's what the AMTA is aiming. I mean, I taught, I talked to Colleen about a lot of this and we have lots of ideas, well-defined ideas about how to make things go.

Dr. Hestenes: [38:02]

But that's a long term project. Of course. Another problem is that the curriculum has to be changed. So you know about physics first. Okay. Lots of people think, well physics, you know, that's the most sophisticated thing. That should be the last thing you take. But it turns out that that if you look through the history of science, that physics really was first. Okay. Because it starts with our moving around the world motion and its causes. How do you move and make things happen and then that expands. And so that's also developmentally kids first need to learn about interacting with things in their environment and then they build up their own mental models of what's going on.

Mark Royce: [38:53]

Physics is really the description of how the world works, how things happen around us, how things,

Dr. Hestenes: [39:01]

I agree with that. Yup. So, um, an important thing to know is about the makeup of the high school physics teachers. Yeah. Most of the physics courses in high school are taught by teachers that do not have a degree in physics. I think only about 25 to 35% of the high school physics teachers have even a minor in physics. So almost all the teachers in our workshops were crossover teachers from other majors. Chemistry was the most obvious one and the most directly connected to physics. But since then we had biology and biology teachers. So one thing about modeling is the modeling program isn't just exclusively for physics, right? The same ideas. We're always ready to immediately generalize or transfer into other subjects to go from physics to chemistry to middle school science. So we have a have a handle now on pretty much the whole STEM curriculum these days.

Mark Royce: [40:17] That's pretty incredible that these modeling methods translate across the disciplines.

Dr. Hestenes: [40:23] That's because it's grounded in cognitive science. There it is. That's why this neuro modeling neural network modeling was not irrelevant to this. In fact, I was working on neural networks in the 80s. In 1984 I was one of the organizers for the first conference on mathematical modeling of the brain. Had some influence, quite a lot of influence actually. So that was in 1984 so that was at about the same time as this stuff that I was doing a neural network modeling also at that time.

Mark Royce: [41:02] What in your mind is the reason that modeling is successful?

Dr. Hestenes: [41:07] Well first of all is it's successful because it is grounded in scientific research and theory. So there is a theory, a general theory about the structure of science, which I call modeling theory and there is cognitive theory about how we understand the world and make contact with the world and that is built into the modeling program from the beginning. So its scientific foundation is there with the, those two aspects. One is the structure of the subject matter and then the second one is the relationship between learning and doing a subject. So that's the foundations. Then the third thing is the community because science actually is a social endeavor. You couldn't do any science all by yourself. It's really a cooperative. And there there is a subject called the sociology of science and so on, although it's not much paid attention to, there is still a lot of sociology in the scientific community. How ideas develop and spread. And in this case, in the modeling community, we have a core idea and then we have people that make contact with others. And so it spreads.

Mark Royce: [42:41] I was in a conversation with a colleague just the other day about the logarithmic rise in the rapid change in technology over the last, I mean, you can just watch this curve from the last 50 years to the last five years to the last year and a half. Yes. There's an increasingly rapid increase in technological development, exponentially exponential. And it's based in the sharing of knowledge

Dr. Hestenes:	43:09	that is a major factor. Yes. That's not the only major, the only factor, but that is a major and the, and that's one of the things that impressed me with the academic world is that the social aspects of it, the importance of institutions, institutions that keep things going, right in contrast to these programs that are supported by the government education programs, they're not sustainable. They're just hit and miss. And uh, anyway,
Mark Royce:	43:43	the motivations change constantly with the government.
Dr. Hestenes:	43:47	Yes, that's right. Different people, everybody has their own ideas. For example, with education, everybody thinks they're an expert in education because they've all been there. They've all been to school. So they, I think they're all experts. But Science, uh, sociology of Science examines what works and why. So I'm very much concerned with that kind of stuff myself.
Mark Royce:	44:14	Do you want to talk about the hope of finding some more funding that you're working on with the private sector?
Dr. Hestenes:	44:21	You may know that uh, Bill Gates put some funding into science education for schools. You know, that stuff had no effect really. Hmm. Because there isn't a unifying idea about what they're trying to do in order to reform STEM education. Right. What is it you have to do? The first thing is to understand that it should be, in my view, okay. Is that it starts with the teacher. The teacher needs to have resources so you get some resources from universities and colleges, but that's not sufficient. And the strongest factor I think is the social connection with other teachers. And that's what the modeling community aims to push. Now I've also have proposals about what to do, but the person who was mainly involved is Colleen Megowan. So she is the number one person for building the community making connection while she's brought some money to the modeling program, we had a little NSF money that's mainly because of Colleen, but um, it's not sufficient.
Dr. Hestenes:	45:42	So I think it's got to have money from the private sector and there, the big problem is there's plenty of money in the private sector, right to support reform. The problem is to get them to understand exactly what needs to be done and give the funding to the right people, the right program. Without private funding, I don't think that there can be any substantial STEM education reform. Ah, okay. It just can't be done. And the best effort to do anything has been from AMTA. That's the best way to do it. The trouble is people that have the funding don't have the connection with the proof. Okay. Right. That's the big problem.

That's another sociology. But it's an extra dimension of the social factors that are involved.

Mark Royce:	46:33	Are you thinking the target for the funding would be a MTA or are there other things going on that you're looking to gather funding for?
Dr. Hestenes:	46:42	Well, I'll just tell you that I am aiming to fund Colleen and have a organization that is directed at funding that will amplify so something beyond the AMTA but that is a way of assisting the AMTA. For example, if you want to make things grow, one issue is you might like to have all the science teachers in a school district involved in coordinating the science activities. I don't actually know of any adequate program school district wide. There are cases where there might be a science supervisor that is fairly enlightened, but now a key issue here is to integrate the STEM curriculum. So we have well-defined ideas about physics first, how it should articulate with biology and the other sciences. The biggest problem in reforming the stem program actually is the mathematics, the connection between the mathematics and the science. Because mathematics education has grown up as a separate community.
Dr. Hestenes:	47:57	In fact, most of the math teachers, well, I've actually run workshops for high school math teachers and 90% of them can't pass the force concept inventory because they, they haven't had any physics or if they have had physics, they still haven't learned it because of the inadequacies of it. So the connection between mathematics and science education is very weak. But we have well... When I say we, it's mainly actually me and Colleen because that's where I'm putting all my suggestions and so on through her because she's the actor and most knowledgeable person on this. Of course, she was also my student and got her PhD under me. I don't know if you know about her background.
Mark Royce:	48:45	Oh, well, a little bit, but she and I have been communicating quite a bit in the last few months, but
Dr. Hestenes:	48:51	oh yeah. Yeah. Well Colleen has really been the number one thing that is maintained. The modeling program after the AMTA was set up in 2005 it probably would have dissipated without Colleen, but anyway, she's the most crucial figure in it. She was a biology teacher. She went to a workshop in Sacramento and she liked the modeling program so much that she came to Arizona so she could learn more about it there and then she got her degree in physics education and ended up with a PhD with me.

Mark Royce:	49:28	I asked you if the funding that you were trying to garner through grants was aimed at AMTA and you said to help fund Colleen's efforts. Are you thinking like a foundation kind of approach?
Dr. Hestenes:	49:40	Well, usually yes, it would be a private foundation, which is usually for individuals that have substantial money, they usually distribute that money through a foundation. Right. One way or another. Yeah. Yeah. Cool.
Mark Royce:	49:55	I'd like to hear how you envision the future of AMTA. What do you see it becoming?
Dr. Hestenes:	50:01	First of all, I'm very pleased to report that I am not necessary for the AMTA. Okay. In the early days when I developed the thing, maybe for the first 10 years after I got NSF funding, I was essential. The greatest success I think is in making myself superfluous, so it's running by itself, so that is an enormous accomplishment. Now it can expand not just in the United States but across the globe. And uh, Colleen has given workshops in Mexico, in Morocco, and I've given things in India. We have connections with the Arab world, there are a lot of connections in Europe so we can easily expand AMTA to a worldwide organization.
Mark Royce:	50:54	Well you still have a lot to offer and I'm really glad that we're having the chance to, to capture these conversations.
Dr. Hestenes:	51:01	I have many published papers go to my website. Uh,
Mark Royce:	51:06	David Hestenes.com?
Dr. Hestenes:	51:08	no, it's a GC website. So that's a geometric calculus website,
Mark Royce:	51:12	yes. So I have geocalc.clas.asu.edu I think that's what it is. Yeah. When I searched geometric calculus, it came up with Geometric Calculus r and d homepage and there's a link there and that is your site
Dr. Hestenes:	51:32	and that has my mathematics background. It has my Oersted Medal paper and there is a section there, a chapter on the website which is about modeling and my papers on modeling theory and modeling education are there. I think you'll find them quite readable. And that has to do with my interest in how the brain works, if you will. So I have a theory of cognition, which I call a modeling theory of cognition. And it's essentially that we understand the world by mental models. And the

		question is, how do we connect up these mental models with what's going on in the world? Anyway, that's the core thing. I will be doing some more of that, I'm sure. And I think that some of this can move into the STEM curriculum with some effort.
Mark Royce:	52:28	You know, it's occurred to me that in the grand scheme of educational reform, this is a rather young endeavor, Huh?
Dr. Hestenes:	52:37	Yeah. Well, I think most of the reform doesn't do much, frankly, because most of it, it doesn't have the research foundation that's necessary.
Mark Royce:	52:48	Hmm. Well, I have thoroughly enjoyed our conversation and it's been a real honor to talk with you. I look forward to potential conversations in the future with you, Dr Hestenes, and me too. Thank you.
Dr. Hestenes:	53:04	Thank you. Bye Bye.