HECHT: I'd like to welcome you and introduce myself, and then begin this morning's convocation. My name is Bill Hecht. I'm a member of the class of '61, and I'm the Senior Officer at MIT for Alumni Affairs. And in the last seven or eight months, I have become one of the dozens and dozens of people who have become involved in the parents program. So on behalf of all those dozens and dozens of people, welcome to MIT.

I want to thank you for doing two things. One is joining us today, but perhaps the most important thing you do is to share those exceptionally talented youngsters who are your children with us. The currency of an MIT education involves two rare sets of talents, extraordinary faculty-- you'll hear from several of them-- and your young people. The combination is rather remarkable, and we owe you some debt, even though you owe us a lot of debt too, for sharing those people with us.

We hope that yesterday and today, you've gotten some glimpse of the kind and quality and intensity of education that your young people have. MIT's education has been likened to getting a drink from the fire hose. I want to assure you they mean not the range but the intensity of the education. We've turned the taps down a little bit, so this is perhaps a high pressure garden hose that we're feeding you in the last 24 hours and then the next eight or 10. But nevertheless, I think you'll go away with a glimpse of what this enormous, exciting, and energized place is all about.

There are, as often is true with great successes, literally hundreds, if not a thousand, people who I should list the name of and thank. I won't do that. There's been one person on my staff, [? Marsha ?] [? Hartley, ?] who is a parent of an alumnus, and would have been the parent sitting in this audience had we started this program several years ago, who coordinated this effort. And I want to thank [? Marsha, ?] the students, the faculty, the staff. We simply could not have done this without an extraordinary outpouring of energy from the community.

This morning it's my great pleasure to introduce the first family at MIT. I often get the pleasure of introducing President Gray. It's rare that I get the extraordinary honor of introducing my good friend, his wife, Priscilla Gray. Priscilla Gray brings an enormous amount of grace and care and personal warmth to this place, and there aren't very many of us who don't feel as if it's a better place because Priscilla is here.

She's also distinguished in one way, and that is that MIT does not offer honorary degrees to anyone, but the Alumni Association has been able to make honorary members. And Priscilla is one of that rare body, an honorary alumni. Priscilla Gray, please.

[APPLAUSE]

PRISCILLA GRAY: Welcome to MIT. Having you here on this campus with us is a 10-year dream come true. I wish to salute all of those on the committee who have worked so hard on this first parents weekend at MIT. You are to be congratulated.

I have concluded in the past few years that being a grandmother is one of the very best roles that life offers. For me, being the partner of the President here at MIT has some of the same wonderful aspects of being a grandmother. Since we live on this campus in the midst of all the students, I am able to see firsthand the intelligence, the vitality, and the stamina the students bring with them. It's a joy to watch your sons and daughters mature, and the friendships I make with them are gifts. I am a fan of theirs.

Thank you for coming this weekend. I hope that you feel a part of this great extended family called MIT.

[APPLAUSE]

HECHT: It's now my great pleasure to introduce, regrettably in his last year as our president, President Paul E. Gray, '54. President Gray came to MIT from northern New Jersey a number of years ago. I won't say how many, but he did get his bachelor's degree in 1954, and if you're as bright mathematically as your children, you can figure out how many years ago. Earned his master's and doctorate here, and save a few years in the company of the United States Army, has taught and worked at MIT for all of his adult life.

For those of us who were here, that has been an enormous gift. Paul brings many talents to the place, but perhaps the best one is an ability to listen to one more voice all the time and care deeply about this place, your children, and its faculty. Paul?

[APPLAUSE]

PAUL GRAY: Thank you Bill. Good morning and welcome. It is an enormous pleasure to greet you on this glorious New England October morning. It's a particularly delightful morning given that we've had four days and four nights of unremitting downpour. And never does a crisp October morning look better than following that.

I would like to express my pleasure, indeed, our pleasure, this place's pleasure, all the folks who are around here, at the number of parents and family members who are here for this family weekend. This is the first time we've tried this in at least 30 years, and now, for a university that is much more concerned with shaping the future than it is with recording the past, its own included, 30 years might as well be infinity.

There was at about this time of the year five or six years ago on the campus a spirited and prolonged debate about the scheduling of commencement. This debate arose because the workings of the academic calendar, as presided over by the registrar, the workings of that calendar had set commencement that May, or June, had set commencement in a way in which it fell on a religious holiday. And so the question was should the commencement date be changed in order to remove that conflict.

Eventually, that debate made its way to the floor of the faculty meeting, because it is the faculty at MIT who control the academic calendar. And if we were going to change commencement, the faculty had to act to do so. There was a prolonged debate in the faculty meeting about the pros and cons of changing the date. And I was presiding at that meeting, and my impression was that the outcome was quite uncertain. I would not have wanted to predict whether we were going to leave it as it was or change it.

Until a senior, a young man in electrical engineering and computer science, stood up and made a brief comment which absolutely carried the day. He said simply that for four years, his parents knew MIT only as a black box into which they poured money, and would we please work it out so that they could come at commencement and find out that there was something else to the place. Well, that remark carried the day, and I hope that you all have in the few days here some opportunity to find out that MIT is not just a black box, that it is a vibrant, exciting, diverse, rich, enthusiastic community.

We hope also that you will share with us your impressions, critical and otherwise, about this undertaking. We expect to do this again, and we hope you will let us know what works and what doesn't work, as seen from your perspective. You will have in these few days many opportunities to learn something about our academic programs, about athletics, about coursework, about the social climate at MIT, and the program this morning is an important part of that.

Before we turn to that program, I want to take just a couple of minutes to say something about a set of subjects with which you are already intimately familiar, and I speak about your sons and daughters. They are, to my way of thinking and my experience, the liveliest, the brightest, most energetic, and inquisitive group of young people gathered together in one place in this nation-- indeed, I suspect, on this planet.

They are valedictorians and academic prize winners. They are football players and cellists. They are math whizzes and experienced actors. They are concerned about their fellow students and their fellow citizens around the globe. They are creative, they are intellectually tough, and they know how to play. In short, they bring to MIT all the richness that makes college the most rewarding time of their lives, and that makes this place a continuously exciting, continuously renewed environment for all the rest of us.

Now, that's not just my view. It's not even just the view of the faculty. We had during this week, this remarkable third week in October, the every 10-year re-accreditation visit for MIT. Every college and university that wishes to represent itself as having accredited programs must, every 10 years, invite to the campus a team of other educators who spend the better part of a week here. They have spent a great deal of time in preparation before they come, and then they will, in due course, within the next six weeks, render a written report.

But at the end of that week, they sit down, the whole team, all 10 of them, with the president, and express over a two-hour interval it took this time, the content of their report and the general conclusions. That team this year was headed by Frank Rhodes, the President of Cornell, and involved nine other individuals from colleges and universities across the country.

In that exit interview day before yesterday, they were clearly tremendously impressed with MIT students. They spoke about the candor, the creativity, the intelligence, the enthusiasm of the student body. One comment, which I think will appear in this form in the final report, struck me particularly, and I want to relate it to you this morning. They said, "we are impressed with the energetic engagement of MIT by its students. There are no listless young people here. Now, you know that all the time. We know that all the time. But it's nice to see that the visitors who were here for four days also were struck by that.

It is, I suggest, because we have students of this caliber, of the caliber you send us, that we can attract faculty of the caliber you will hear from this morning. Students and faculty are the two sides of the coin of excellence at MIT. They go together. They are inseparable. You won't long have a good students without a strong faculty and vice versa. Faculty come here, stay here because of the opportunity of working with young people of such capacity.

Our first presentation this morning has been prepared and will be conducted by Phillip and Phyllis Morrison on the subject "Footprints in the Rock," that is, how to tell something about the creature who made the impression, whether that imprint is one hour old or more than a million years old. Phillip Morrison is Institute Professor Emeritus. He is one of the premier physicists and science educators of our time. He's been on the MIT physics faculty since 1965.

Phil displays an extraordinary range of interests and talents, astrophysics, science education, the history and philosophy of science, the role of science and technology in society. He is known surely to many in this audience as the man in front of the camera in the PBS series *The Ring of Truth*, which he developed with his wife Phyllis.

Phyllis Morrison is a writer, a weaver, an educator, a frequent collaborator with Phil on their many projects. She was co-author, co-participant in *The Ring of Truth* and co-author in the book that went with that series. She is a passionate believer in the ability of science and technology to play a crucial role in maintaining the diversity of life on this earth.

Both Phyllis and Phillip Morrison are dedicated to demystifying science, a critical matter these days when so many issues affecting the quality of our lives-- indeed, the future of this planet-- depend on a broader public understanding of science and technology. It is my great pleasure to present Phillip and Phyllis Morrison.

[APPLAUSE]

PHILLIP MORRISON: The black box is a powerful metaphor out of science and technology. We all know them, even though nowadays sometimes they're brushed aluminum with lots of knobs and buttons. Of course, opening the black box is also a powerful image, and that, I think is the best [INAUDIBLE] I can say for what we mean by trying to do science. To get people [INAUDIBLE] by looking-- not fully. Most of the world remains a black box to science and technology today-- but looking into it, then to find our way inside that structure.

Now the wonderful part of it, turns out after 30 years of doing it, turns out to us to be that you do the same thing, whether it's the general public, such as whether you're watching a television set, or whether it's the properly praised students at MIT, the beginning is much the same. The style is much the same. Of course, the valve is turned on higher for those who will be professionals. But there is no difference in the quality of what you do. You can't do it without a vehicle for presentation.

We've chosen a title. It has a rather nice metaphorical ring. But we also mean it quite literally. We hope you'll think about it both ways. We're going to talk about footprints in the rock, what can be squeezed out of them, which is a simple introduction to the broadest methods of science and engineering.

PHYLLIS MORRISON: Now that title, "Footprints in the Rock," is a perfectly good all-purpose title for almost any talk you care to name. But today, we are going to talk about, literally, footprints in the rock. And I think that distinction, that concreteness, is a piece of what Phil and I try to do as we present the stuff of science, whether it be by entering your living rooms or teaching freshmen. Some of you have seen us in your living rooms, and we are working right now on a freshman physics course with hands-on experiments in it. Some of your kids will be in our classes.

That business, the results of science, are very easily available. That's all around us. But the behind the results is the stuff itself, the way science is done. And a year ago maybe, Phil became a Brown study as he read yet another book. This one had footprints in it. And he was caught by and thought about that. And we talked about it and tried some things out, and then thought about even more footprints, and that is what we'd like to bring to you this morning.

PHILLIP MORRISON: There are two points that we hope this is giving an example for. First, that science has to do with the concrete and the particular, which is usually not just what the lecturer writes at the bottom line. That's very thin. The bottom line is what people talk about. But it's not that. It's the enterprise that describes that is the important one in science. And so it's not only concrete, but it's concrete in a context. It has many things around it.

And second, it can't be done entirely passively. I read and write a lot. I'm a professional book reviewer. So I hold books very high. But they are only opening a gate. To walk on the path, you've got to do more than books. You've got to at least work. The book at least gives you a chance to turn the pages and go back and forth, which I have to say, the video screen does not do for us yet.

And this is the other side. You must be to some degree participant in the activity in order to make some progress in science. Do you think that this is the science? Those words the poet might have said. That is not the science. It's what they mean that counts. And that meaning is broader than any formulation. And that's what we're going to try to show in a very simple but quite romantic context of "Footprints in the Rock."

I would like first to take you to a different landscape, and the first slide may reveal this for us. It is not unfamiliar. I hope that some people in the audience will have been there. I never have. But I admired very much the distant desert aerial scene, and you can see the a ravine and a rather deep gorge going across the front of the scene. This is the famous Olduvai Gorge. Very important, because around it in the region that you see here, this region covered with volcanic ash and lava flows, a desert scene, is part of the ancestral home from which our species, after many years, descended. In this region, there's, we'll show you, the direct evidence of the life of those beings, those ancestors of ours, who are not of our species, who we would recognise as on the way, but not yet present in this scene.

Now, within the 20-mile stretch around this scene, there lie to your right on the horizon-- we don't see them here-- a couple of old volcanoes, those which are responsible for this flow. And to the left, downstream from the end of the gorge, the land slowly tilts and gives way, water courses, cutting through many layers of the ash down to a salt lake 15 or 20 miles away.

This is a very strange landscape. It looks a little Arizonan. I know the desert of Arizona and New Mexico pretty well. But it's probably stranger that we don't have such recently active volcanoes with their outpour.

Now I hope you have this feeling of what's going on in this land. And of course, there are animals in this land, especially in the rainy season. At the end of summer and the monsoon, there will come the rains, and the land will be greener than it is here, and a lot of animal life will appear. They are hidden and move back and forth across the area seeking higher ground by dry time, and going down to the lowlands in the winter time.

The famous contentious family of Leakey's premier archaeologists and paleoanthropologists worked here, as you know, for 50 years. And about 50 years ago, 45 years ago, they were told by a Maasai friend who stopped in to watch the work looking for bones on the edge of the Olduvai Canyon where they very successfully found many relics, they said, well, you go downtown 15 miles from here to a place called Laetoli, which means the Place of the Red Lilies, and in that lily place, he said, there's a lot of bones on the ground. A lot.

And they took note of that, but they didn't go there for some years. They were pretty busy. When they went there, indeed, they found a lot of bones in Laetoli, very few of them hominids. Almost none. But in the course of that investigation, they found many remarkable things. And the second slide will show something of what they found.

Well, these are birds' eggs, fossil birds' eggs, half petrified, dug from the ash. They are the eggs of the guineafowl. You can still see this wild bird freely around the region. Birds haven't changed very much, and in the next slide--

PHYLLIS MORRISON: These are fossils?

PHILLIP MORRISON: These are fossil eggs. They're not new eggs. They are rock-like. And here, you may see the track of the guineafowl. This track is not a track in the dust. You will see those, too. This is a track in hard rock, the congealed ash which we call tuff, which dominates the landscape, just what you saw there. And the very same tracks can be found there. Guinea fowls are conservative organisms. They haven't changed very much since this became lithified.

PHYLLIS MORRISON: Now, what you'll have is layers and layers and layers of tuff, of the stuff that blew out of the volcano. And essentially, those are the pages of a book of time. And as you flip through those pages, which the river cut the gorge made possible because then you see them on the sides of the gorge. You go down, down, down in time.

PHILLIP MORRISON: It's exciting to find a place, and they found it, a page in this book, which is exposed here and there by chance. Often, it's covered by other material. Often it's covered by heavy lava flow. We'll never get to it. But here and there, the chance erosion and flow and bowing of the winds in the long past has revealed a certain layer. Actually, it's a few pages. It's maybe five inches thick. And in those five inches, you can count 10 different layers by their texture. And by little partition, the texture, as you cut through it, you can see, yes, it was not the same here. Little coarser and a little finer, little coarser, and then a little finer-- that sort of marking gives you the pages.

I should say, this book is quite thick. It is 500 or 1,000 feet thick. If you go all the way down to the salt lake, crossing layer after layer after layer after layer as you go down, you can build all those up. But only in one place, only in six inches of that entire thick book, there is marked a lot of footprints like this. And they found and exposed them. When the expeditions went there in the '80s, the description has now been made really as a time of the '80s now. It took many years to bring suitable experts there to spend a long time to study what was there.

Maybe 30 places or 40 places, a few acres each here and there across the place of lilies, a five-mile square some distance from Olduvai Gorge, they found the exposed, gray-brown hard surface that they call the footprint tuff. And when it wasn't quite exposed, it was close by, they would cut it away a little bit to see what might be found. They knew it was a significant layer, and that was of course the early discovery made in the '30s. It tool a long time to get around to studying it.

Here is someone at work on the footprint tuff. Next slide please. There you see her, one of the archaeologists. And if you look more closely, you'll see she's looking at a very big footprint, which turns out to be recognizable as the footprint of an elephant in hard rock.

Now I'm not here to describe the ology of that time. I'm not a biologist. I'm not a paleontologist. I'm a simple physicist, and I'm interested in the physical situation that we can learn from these things. But I'm especially anxious to talk about the context in which these particulars occur. It is not just the headline. It is what goes behind it. Here you see, the front shows you a very nice large print, which I think looks elephantine. And it's pretty impressive that these things are there.

But now what astonished me-- I had read the articles in the magazines and the newspapers, and I knew that the Leakeys had found wonderful footprints of ancient beings and our ancestors there, hominids. What I didn't realize was the depth and richness of this context. I was, I must say, frankly a little skeptical. How could you find and interpret correctly a trackway of 50 footprints in the whole history of geology? Why should that be meaningful? Why can we believe what they say? And it wasn't until I read the great, thick expedition report-- that was the book that Phyllis talked about-- that threw me into a feeling of genuine understanding for the first time, appreciation of what these people could do.

All in all, they discovered in these 10 or 15 areas that they studied, 30,000 tracks in the footprint tuff, all in the rock, all in the same few layers. All made, therefore, within the time of a few falls of ash from a distant volcano. Not very distant. Across the horizon. Most of those tracks were recognizable today. They got a local hunter, a skillful tracker. He said, yes, yes. That's the track of a dik-dik, one of the little antelopes, or the track of a hare. The hare and the dik-dik are still the most important wild animals of this region, and they made up maybe half the tracks.

But the rest of the tens of thousands of tracks, he could, the tracker, identify many of them. And the experts who came from all the museums in the world all over the world who knew their animals could recognize, yes, they were this, that, and the other kind. Generally, the species were not the same, not exactly. This is a long time ago that those tracks were made. It doesn't lie at the top of the present land. It lies way down, as you go downhill towards the lake. And we know the dating, but I'm not going to talk about dating. We know it was a long time ago. That's all I want to say. Much longer than any witness can possibly bring to us. Only the mute witness is present. And these 30,000 prints are the subject of what we want to talk about.

That's what gives reality to the interpretation, it seems to me. It isn't just a chance, one or two things. It might be a fake. It might be a misunderstanding. But it's in the context. They're all over the place, and they cross each other, and they interweave, and they spell out the entire list, the ecology, if you like, of living forms of some distant time. Preserving, in a very strange way, a single page or two out of a book of millions and millions of yearly pages, just one page is exposed to us-- even the ephemeral passage of some little animal leaving hoof prints in the dust, which was there. It was not rock then. It was only dust.

Now, I guess the first print is worthwhile. This, of course, is a marvelous object. It's a contour map of the print which they call a hominid print. Contour maps are not the easiest things to read, but I wanted to show it just to emphasize the care with which these matters have been studied. These are millimeter contours. They photographed it stereoscopically. Specialists were brought in that can do that. He spent a whole summer photographing all footprints of human beings. Not the 30,000. Only 40 or 50. They spent a lot of time on them, and then they made these maps to send them all over the world and publication so that everywhere, people who knew about feet and about walking, about orthopedics and about gait and about prints could study in detail the material as well as they could represent it. So this is the footprint of an ancient ancestor, and I'll say a little later something to give you some feeling for how old that print actually is. But that's not my main task. And the next, I think.

This is a map again. It's the map of the trackway. I think you can see what it looks like. Here is a collection of footprints. Here is a big gap where a fault has come across that since it was made, one indication of the age. Of course in California, it might be two weeks. But it is something. Phyllis has pointed out the set of tracks, little and big, that go together right across the footprint tuff.

This is a wonderful discovery. Some very alert archaeologist noticed just one print, which he said looked to him rather humanoid. Nobody believed him. They all trooped around to look at it. That was right. And then they began to take away the two or three inches of tuff that remained above this rather hard layer. They could take it away at its parting layer and uncovered a whole trackway until they ran out. And this is the trackway, as you see, some 40 step prints or so that represent all we know of the situation.

PHYLLIS MORRISON: Now, What do we know of what has made these tracks?

PHILLIP MORRISON: Yes. We would like to know. We can't doubt from our experience with footprints since Friday was discovered by Robinson Crusoe, we can recognize that footprints are the sign of some quick impression on the rock, maybe 30 seconds or 60 seconds of walk. And that's all we have, a snapshot seized out of the past, a frame grabbed, if you will, out of the long movie of history. And in this frame, we're going to try to find out who made those tracks, how they were made, what else can we say about them. And we can say, of course, quite a good deal.

Next, I have to say this already was on our wall when the book came. So it wasn't something that we made. I'm not sure if the authors of this record are here, but I think maybe they are.

PHYLLIS MORRISON: Are the Adamses here? Would they be willing to walk across the stage so we can see your heights and your feet as you walk past?

PHILLIP MORRISON: Now, these are hominids, clearly, of our species. Very detailed prints, because it's much better to have ink and paper than it is to have tuff millions of years old to work on. See a lot more detail here. We have no doubt about this. But it's very nice because we can present the actual specimens. You don't often get to do that in paleontology, and this is really good stuff. And when they appear, I think you'll have no doubt which is which. I'll simply say we have [? Dar, ?] Mary, Jake and Ben Adams who kindly sent us this. But I have to say, this is really something like paleontology because they're not the way they are now in these prints. This is the newborn print of the youngest of the family.

[APPLAUSE]

Now like a proper physicist, Phyllis has marked the scale on this picture, 10 inches, and we will draw upon that from time to time. This is an exercise in measuring space and time, as you will soon see.

OK. Thank you. That's very good. And now then, we want to show another remarkable thing you can get out of measuring footprints. This was astonishing to me, but I should, of course, have anticipated it. Of course, we have made here a graph. This is an extremely simple graph, actually. We didn't make it. It was made by the paleontologists who reported on the Place of Red Lilies and Laetoli.

Here is the length of a footprint. Here is the stature of the hominid that made that footprint, in this case, all living human beings but two dots. And these dots represent 50 years of anthropological investigation. The dots usually represent the average in a well-defined population of people. Very strange populations. There is an average of 500 persons chosen at random in some city in North China in the '30s. There is the average of 100 Smith College students. And so it goes. People with shoes and without shoes, tall people and small people, all kinds of people are represented in this curve. Very interesting, but I can't go into all that detail.

However, I will show you that on this point, here is G3. Now G3 is the length of the footprints that we saw-- the trackway footprint, of which I gave you a map not long ago. That's the length of that one. And this is the length of the little one that went beside that. On the map, you saw big prints and small prints, the larger one and the smaller one, those two points. And they were not measured by anybody. They were measured from the tuff. But they fit the line really surprising well.

PHYLLIS MORRISON: No, they were put on the line because we only knew--

PHILLIP MORRISON: Yes, yes. We only knew the footprint size, so they were put on the line. Thank you. They established a point. But they used this line, which is the average line of all these things. Well, you might doubt that a little bit, so we produced some data of our own in a participatory way.

PHYLLIS MORRISON: But when you put them on the line, you then were able to read their height.

PHILLIP MORRISON: Yeah, that was coming. First, we'll talk about how good the line is.

PHYLLIS MORRISON: We added some data, and--

PHILLIP MORRISON: Can we put the last one on?

PHYLLIS MORRISON: Ah, yes. Let's move this a bit. We had a friend--

PHILLIP MORRISON: We had a very tall friend.

PHYLLIS MORRISON: --even up there. But of the four people who just walked across the stage, here's [? Dar, ?] here is Mary, here is Jake, and here is Ben. Ben is so far off the line that I suspect he is going to grow up to be a very tall person.

PHILLIP MORRISON: But that's only a vague forecast. We're not sure of that. But of course, now I must say something to disabuse you. I was quite puzzled by this because it fits so well, and yet we know you can't just buy shoes by writing to the shoe shop your height. And the reason for that is that we like to have our shoes fit within an eighth of an inch or a quarter of an inch, and that won't do. A shoe size is something like an eighth of an inch.

These are broader errors. We allow that. But those who know some statistics will know, this regression coefficient is 0.94. That's to say, 95% of the variation-- I'm sorry, I moved it.

PHYLLIS MORRISON: I'll fix it.

PHILLIP MORRISON: --is given by that nice, straight line. An extremely simple relationship between the height and the footprint length of people roughly independent of where and how and what they are. This friend of ours was 6 feet 7. This friend of ours is three 3 feet and 1/2. And yet, they lie-- these green dots, which we measured ourselves, we didn't trust all those 50 years of anthropologists. But by heavens, they were absolutely right. And a little error doesn't make a lot of difference.

So I think we can successfully read off this graph and say very likely, the being who made the bigger print in the tuff is this person, this hominid, about four feet, a little plus four feet. And here, four feet and a half, and here, a little bit under four feet, the accompanying print, these two tracks that went together.

Then here you will see the map of the tracks. Here's the larger one and the small one. Notice that they accompany each other very well. They're in step. The experts on footprints say there is very little doubt that that was done by the two creatures walking hand in hand. Otherwise a small person, who you'll see soon, cannot really keep pace with a large one. There has to be an kind enforced rhythm. And indeed, they showed breaks in the rhythm in the small step where the small gait has had to break the rhythm in order to catch up a little bit with the hand holder, who was moving ahead. So remarkable affair.

I have to say a little bit about how these prints were made. It's really quite interesting. You recognize that these creatures are co-specific we believe. Species are hard to define in the path. There are very few data, only a few skeletons, a few bones, a few skulls. They make much of it, but they make more, I think, than is recognizable. This kind of material is better than the placing of the few remains they have into group by species. But the famous hominid Lucy is about the same age and about the same size and nature, fully bipedal, as these two-footed walkers across the ash.

Now how come that this footprint can be preserved in the whole footprint tuff? How does it work? Does that make any sense? It does make remarkable sense. I don't want to describe it in detail. I'll simply say that the volcano that made this tuff is lying there in ruins 20 miles away. We can look at its crater. We can sample its chemistry. It has a very unusual chemistry. It puts out an ash which is a mixture of volcanic ash, pumice, and washing soda-- sodium carbonate. This material, called carbonatite, and when it changes, we call it [? trona, ?] is mined extensively in Wyoming and Saskatchewan in million-ton quantities each year to supply the glass and soap industry of the North American continent. That was, too, an ash fall from a volcano of a strange kind.

Now, that kind of ash, as you recognize from just mentioning washing soda, when water falls on it, chemistry occurs. The rain came. The ash dissolved in part. And when it dried, it had cemented the particles together with the [? trona ?] that is made, as it is called. And that mineral is much harder than the ash solidified on either side above and below. And it's that that took the footprints and held the footprints so wonderfully.

So we know the rains had to come rather soon. We know from measuring the thickness how much ash had to fall. We know that the whole season does not occupy very much, that this track is made in a time small compared to a season, because you can see the rain come and the dry season alternating through the ash, just as it alternates today. So they can say with good probability this was made in the early fall, when the rains came on top of a strange fall of ash from the volcano, which of course, did not occur every season, but occurred very frequently.

And indeed we may suspect from the orthopedist who had said, these beings are walking through there very cautiously, that they were walking in a darkened light of day, darkened by the heavy ash fall. And they were undoubtedly afraid-- we can impute that to them-- of the circumstances.

PHYLLIS MORRISON: Some places in this layer, there is even preserved for us the splats of the rain drops.

PHILLIP MORRISON: There is also across this track-- not shown here, but a little off this trackway down here-- the crossing of a horse, which is a very nice thing to see, because unmistakable horse's hoofs-- I don't want describe it in detail-- but that horse is making footprints and stride distances that are quite small compared to any horse or pony you can find today. And in fact, there are two. You can imagine there's a good bet that at least one was rather adult. Most horses are adults. Only a few are young at any time. That horse can be shown to be walking in a gait that is like that of the Icelandic pony in difficult circumstances. The smallest of all our modern ponies, and this horse is even smaller than that.

Well, you know that when small horses existed, it was not very up to date. There are not horse's left any longer in the Serengeti Plains. But if they were they would not be 3 and 1/2 feet high as these horses are, some indication of the age. And the remarkable thing is the gait of this horse is the same gait the Iceland pony uses called single foot-- horse people will recognize that-- which you use when the footing is unstable and slippery. A horse picks his way across moving the two feet delicately in the rhythms of the floor to carry out the gait called single foot. And these beings are also worried about the slippery slope on which they are moving.

So that's the story, and it gives us an enormous sense of presence. I think it is fair to say that two hominids walked across this in the darkened and poor visibility of an ash fall on a slippery, early, recently wetted soapy kind of ash, afraid of slipping and falling and not able to see very well. And their heights were, as we've indicated, learned from the footprint. So all that comes out of reading footprint size. Should I show the last? No. We're going to save it.

This very remarkable story of what has to be a minute, which can certainly only be a minute of alarm and concern, and the fact that the older one and the smaller one walk exactly at the same gait, not running back and forth means they were certainly made at the same time, and probably made-- you can't see the hand motion, but it's very easy to understand that these completely two-footed creatures, who never put their knuckles on the ground like the chimpanzees, but are erect as we are, though they come from a time when horses were small, when lions and tigers both lived in Olduvai, saber tooth tigers at that, then we know this is not the present day. I don't want to talk about the dating, but it's actually about 3 and 1/2 or four million years ago that these tracks were made.

And out of that moment we pick this kind of thing. Not just from the headline, not just from finding these tracks, which of course are wonderful, and have acquired a great deal of study, but from the whole context of 30,000 footprints around this five-mile square piece of the Place of Red Lilies. It's really a superb and romantic story, and I don't want to talk about it exclusively.

One could stop, but we wanted to go on further because physicists like to have time as well as space. All this has been about space. But we're going to do something now about time, too. Because what is still more remarkable is that you can read time from footprints as well. Phyllis.

PHYLLIS MORRISON: Not the vast amounts of geologic time, although for this next piece of our story, one needs to go back a great deal longer in that book. But not to the celebrated gorge of Olduvai, but to the cut, the Connecticut River has made in New England and Massachusetts and Connecticut, particularly. In the 1830s in that valley, in many places, but for instance in the town of Turners Falls, when the new sidewalk slabs came from the quarry, they contained footprints too. And these footprints were first thought of rather as the footprints of giant birds. Not a bad first guess. There is a wonderful little state park right on the banks of the Connecticut where you can go and see such footprints in place on a slab of rock above the river, and I recommend it to you. So I have seen them myself. These particular ones appear in a publication of a man, Edward Hitchcock, who taught at Amherst College. And down in the basement of the geology museum there, there is a vast array of footprints of dinosaurs, most of them wonderfully collected in the middle of the last century when the discussions raged about what this was.

And before too long, they came to understand that they were not quite birds. It was a big argument then. Perhaps today, we see a closer connection between the giant reptiles and the birds than those people did. But that was there. Soon, from England and then from the marvelous deposits in the American West, the bones of the great beasts came too. And they have certainly been favorites of many of ours in all that time since.

PHILLIP MORRISON: So here we have a way-- we are jumping in geologic time far, far back, far, far back. As you know, the cave dwellers of our ancestors did not fear dinosaurs. They didn't know a thing about them. They may have found an ancient bone or two, but this is far, far back, much older than the hominids. And now the next print will show the kind of-- we have all over the world, the searchers have now found about 1,000 localities where there are dinosaur footprints, amounting to hundreds of thousands of prints. So this is becoming a study much richer even. Of course, over a long period of time, so many, many examples, and many, many forms of animal, and over a huge period, it's not easy to summarize in any way.

One of the most exciting, though, is this reproduction made here, a drawing of a place in northern Australia near Brisbane, Queensland, Australia. And there you see footprints, and I think you will see quite clearly this dramatic event. There are footprints of a very large creature. That's a two-foot pad, that footprint, that footprint. Those two-foot pads almost full size. Just about full size. You imagine how big that is. So the rest of that animal, all we see is his footprint. He's a pretty good sized animal-- or she, for all that matter.

And these little fellows are also bipedal dinosaurs. They are turkey-like. More or less, those are the prints of turkeys, big turkeys or very big hens and roosters running along. And it's quite characteristic of these hundreds of prints all going this way and these three big prints going that way, and we'll see what we can reproduce from that a little bit later. But that's an interesting part of the puzzle. People try to interpret these scenes. Again, a flash out of the film of all history.

Let's look a little bit at what we can say about time from a footprint. It turns out that when any creature walks or runs, there is an enforced relationship between the length of the stride and the speed of motion. This comes out of the physics of motion. We don't fully understand the control mechanisms that allow almost all creatures to run efficiently at a number of speeds. When they run, they can't change their posture and space and so on easily. If they try to do that, they will have a hard time performing. We are built to have a rather well-defined engineering of domain of behavior, which makes us walk and run.

As you run, as you know, you don't keep both feet on the ground. In fact, running can be said to be, that motion in humans when both feet are not simultaneously on the ground, you take off by pressing one foot hard against the ground, beating gravity. In order to make the speed high enough, you must push hard. When you push hard, you overcome the effect of the weight, and it breaks contact with the surface. And this is a necessary condition of running.

And it therefore turns out that all sorts of animals have a quite straightforward relationship between the stride length, which is here defined simply as the distance from the left foot coming down to the left foot coming down again, to the left for coming down again, for all these bipedal creatures-- I guess even some four-footed ones. In that case, you go through the whole stride. You have left to left, left-front to left-front, and so on.

These various curves, they're each rather good curves. Notice the cluster of dots of each kind. But I observe to you, this is dogs. Here we have the length of stride. Here we have the speed of motion. So the faster you go, the bigger the stride. No doubt about that, as we'll show in a moment. And you make that plot, I get this graph for dogs. And these circles are humans, adult men in this case. The squares are dogs, and the triangles are camels. And they all have curves which look like rather plausible straight lines like our height curve, but they're not at all the same curve.

Well now, can we learn something about the speed of an animal from its stride length? Well, clearly we can. We make many tries. We get a line like this. We find the stride length, and we find the speed right on the same curve. That's very good. But that works for camels. It's very poor if you apply it to dogs or to men. No way. I think even ostriches are somewhere-- no, they're not on this slide. What can you do? Because we'd like to know about dinosaurs.

But alas, we are absolutely unable to take a series of small, real size, big dinosaurs, run them along the trackway and measure this lovely curve. It would be a wonderful thing to do, but I venture to say unless in some distant planet, the way the science fiction writers do it, we'll never have that opportunity. But the structure of nature is tight, and the physicist understands that we don't understand running and walking very well. Here, I draw very heavily upon the work of R.M. Alexander at Leeds University and [? Taylor ?] and [? McMahon ?] up the river at Harvard University who have done the most of this kind of work in the past 10 or 15 years.

And they have shown very beautifully the following remarkable unification.

PHYLLIS MORRISON: With these data spread out all over the graph, it's clear that you're in trouble when you want to tackle the dinosaurs. What one needs is some way to unite those. And the trick, here, it has been done. And the trick is quite wonderful. You plot the speeds in relation to the size, and you plot the stride length in relation to some piece of the size of the animal. And

When you do that for all the animals we know, the spread pulls in, and we get a line which is what the physicists like to call dimensionless.

PHILLIP MORRISON: Yes. The dots of this line have different kinds, as you see. I will simply read you the legend. "Ostriches, humans, dogs, elephant, rhino, sheep, and camel." All of those animals, every dot in the stride length vs speed curve has been, as we say, reduced. That is to say, a calculation has been made to take account of the scale, the size of the animal's hip height above the ground, because that's what determines the push. And the effect of gravity and speed in determining the energy, we make both of those. We scale both of those. The physics students will understand.

And the simple calculation on each dot, without, I think, unprejudiced way, the dots go onto a curve. And lo and behold, all the species, because they're all sufficiently complicated vertebrates, that they have the internal electronics to adjust themselves in the right way to do the efficient walking, running in each case. And they enormously unify. Of course, not perhaps good enough to get a shoe size, but amazingly enough, to show whether you're dealing with a large animal or a small one. Simply from the relative stride length and the dimensionless speed, you can tell how fast an animal is moving-- how fast it is moving merely from the size of the print, which gives the stature and hence, the hip height, and the space between prints.

So the footprints have frozen not only space, you might believe that, but they've also frozen time in the sense that the speed is written in the footprint just as surely as the height of the animal we discussed, the hominids. That remarkable result is what we see here.

Well, it helps to be skeptical. You don't make any progress in science by believing everything that you're told, not what I'm telling you. Question authority is the first requirement, like the bumper sticker says. So we questioned it with the help of some students, and here is what the answer became. Perhaps you can see the green points. They are not very terribly clear. In fact, it's better from our argument to say there are six green points there chosen randomly from about 40 green points, which we caused to be made last week with the wonderful assistance of the students at experimental study group, [? Amet ?] [? Laff, ?] a physics student who took responsibility for giving us the papers, and six persons.

We took one of these dots, men and women alike, large and small, we took one of these dots, fast and slow. These people were walking, running, jogging, in every case, simply timed their motion and counted the strides to go across a fixed distance. And those points merge right into the background with ostriches, camels, rhinos, freshmen, you name it, all highly skillful species of vertebrates who know how to walk, run, jog, et cetera. And there they are.

PHYLLIS MORRISON: So then another story comes out of this event.

PHILLIP MORRISON: Let me say a little more about that. The fact that it fits is really unmistakable. So now we can look at footprints. Now, you have to get the size of the creature from the size of the footprint. Then you must get the stride length by looking for the successive footprints. And the patient paleontologists have worked out of this jumble of turkey tracks, not every one, but they've got a number of trackways, and they can identify exactly the right size of foot, and it comes down in the right order, picking out of these a particular trackway. Somebody pointed out to me some of these trackways probably should disappear. They don't have them anymore. That may be well true. Because they discover the following.

It's clear that these prints superpose. They weren't made at the same time. And the formation, which this is preserved, the rock, is such that at the end here a few feet away it changes nature. And the geologists say, yes, that could very well be a shoreline at the edge of the pond uncovered in the past. And this big object, who is a carnivorous dinosaur 25 feet high, was walking rather slowly for him or her along this way. And these little fellows, who are mostly herbivores about the size of turkeys, a little smaller, are running pell-mell against the walk of the big one. And you get the drama very, very clearly. There's only one way to go, and they've got to run right at that creature. And of course, very likely, a few disappear because this one reached down and got a breakfast out of some of the hundreds passing. There are 4,000 prints in this Australian site. It's one of the best treated paleontological sites like the hominids at Laetoli.

PHYLLIS MORRISON: And are the little ones walking?

PHILLIP MORRISON: The little ones are running pell-mell, and we understand why very well. But you can tell that not just from the juxtaposition-- that's a guess-- but from actual measurement of the track height. Is [? Amed ?] [? Laff ?] here? Did he make it? OK.

PHYLLIS MORRISON: We thought we would show you how it's done, but we're also running out of time.

PHILLIP MORRISON: We're running short of time, so we needn't do this. But we simply measure a place. We let somebody run, walk, jog, whatever you like, doing it carefully, trying to keep it the same speed, that's all, and counting your strides, counting your steps as you go. And then with the distance, the number of strides, the height of the hip, and the time, you can find a point on this great unified curve.

And notice just what is happening. That curve doesn't change. We know that running begins when that lower number across that curve reaches a certain value. And to the left and to the right, it looks much the same. This curve has unified the whole story of locomotion.

Well, that's it. The story goes back very far. We don't really want to say much more about it. But what we have tried to do is emphasize two things-- that results in science are not the whole story. The process is ultimately important. In order to understand and believe what they tell you, it is not enough to have the headline.

On the other hand, it's very easy to gain some grasp. You don't have to drink the whole fire hose to taste the water. And that's what we're trying to do. But you do ought to be close to it. You can't rely only upon that distant screen. Participation, we do it all the time. The world is everywhere. You too, every time you walk, run, jog, canter, whatever it may be, you're bound to be making a point on that unified curve, even though you don't know it.

And this is the kind of thing we'd like to say about teaching science, and we think it's the way to go, both at the level of the stranger who turns the television screen on knowing what he's going to see, or the apprentice who's going to do much better than we did by investigating all sorts of things. And that's the freshman student or the more advanced student that you know too well who's sent here.

So I'll simply close with a dramatic slide, and I think that's all I have to say.

PHYLLIS MORRISON: The last slide?

PHILLIP MORRISON: Can we turn this off somehow?

PHYLLIS MORRISON: Yeah.

PHILLIP MORRISON: The final slide, just to remind you what we were talking about. This is the slide, can't represent it very well, showing the hominid footprints in the tuff at Laetoli, a moment out of the past of our genus. Ancestors smaller than us, not so clever, fully erect, fully two-footed, wandering along with a sense of unity as they cross the slippery, darkened path, long, long ago in the Place of Red Lilies. Thank you.

[APPLAUSE]

PAUL GRAY: We have a few minutes. If folks would like to address questions to Philip or Phyllis Morrison, we'd be glad to entertain those. There's some microphones in the aisles, I believe. I can't see out there terribly well. But if anyone would like to raise a question, do it from your seat, speak loudly, or go to a microphone. Could you turn those lights down a little so I can see if there are hands up?

AUDIENCE: I have one very easy question. Has this been published yet?

PHILLIP MORRISON: No. Not public yet. However, I can refer you to two excellent books. Let me skip one of them. It's pretty technical. A book called *Dinosaur Tracks* and *Traces* published in 1988, University of New Mexico Albuquerque is a paleontologist treatise on all kinds of tracks from dinosaurs. R. M. Alexander published a book, Columbia University Press, 1989 called *The Dynamics of Dinosaurs and Other Giant Beasts*, which is a popular book, very beautifully done, from which some of our best pictures came. R. M. Alexander. I recommend these books thoroughly.

There's a lot of work on this. A very good book called *On Size and Life* by Bonner and McMahon, Scientific American Library, published about five years ago is also a great introduction to this.

PAUL GRAY: Yes, please, sir.

AUDIENCE: Just a question about the physics of stride length and speed. I'm wondering if there's anything more that can be said about a unifying mechanism. Does it have anything to do with falling speed? And also, why are the two-legged and four-legged animals-- why do they fall in the same curve? Maybe that's the same question.

PHILLIP MORRISON: Yeah. This goes a little further into the physics than probably it's fair to do for a completely general audience. But let me put it this way. The simplest thing I can say is this. Suppose you consider the operation of having your foot down when you're making progress horizontally. You see how-- no no. Foot down. Right. Now roll over it. Walk past.

If you look at that a little bit, you will soon get the idea that the forward speed controls the rate of change of angle as you go across the vertical there at the top, when there's not much action against gravity. Now that motion is rather like an inverted pendulum. The key parameter that will occur there is the ratio of your kinetic energy in the horizontal motion to the potential energy that is holding you up that essentially, you have to overcome to leave the ground. And as that speed rises and rises, calculation will show that the thrust against the ground which you have exerted by using the muscular energy and the elastic energy of the tendons is enough to push the ground hard enough to accelerate the creature into the air. That is, it overcomes the weight.

So the relationship between the weight of the animal and the speed of forward motion is built into that phase of every stride. It really doesn't matter whether they have four feet or six or two if you're moving in that general way. Now, that's not enough to explain the whole story. We can't do much more than that. But it is enough to allow the scaling to say well, two such organisms, if they work rather well on the same way, should have the same behavior. If I plot two dimensionless quantities, the length that's the size of this motion against the size of the creature, that clearly takes the size out of it, enabling us to compare dogs and camels.

And then the other thing is I calculate the ratio of the kinetic energy of horizontal motion to the potential energy of vertical motion, I take the square root of that to get the velocity in the first power, and that gives me a dimensionless number. It's called Froud's number. It's very well known to the Naval architects and engineers because exactly the same thing controls the behavior of ship models who throw up a lot of energy against gravity in the wake of the ship. That controls the motion of ships for a very large part of the useful speed of ships, sailing boats, and steamers alike.

And in the same way, the details of how many legs you have is not very important compared to the fact that every leg is fighting gravity as it rolls over the edge. And the amount of fight depends on how fast it's moving. And putting those things together, you can get your dimensionless quantity. And that turns out to work extremely well. We couldn't stay in advance what will work. It's not a complete theory. But it turns out that the organisms are working to optimize something in such a way that that really works well.

PHYLLIS MORRISON: The students who made the data are indeed here, and maybe we could at least get them to stand up.

PHILLIP MORRISON: At least. Let's, yes. That would be very nice. The experimental ESD.

[APPLAUSE]

PAUL GRAY: One more question. Yes sir?

AUDIENCE: My question is about all your data is being collected under the existing gravity, whatever the force of the gravity is now. Would the gravity be the same three million years ago?

PHILLIP MORRISON: That's one of the most wonderful things that we know to good approximation. The gravity has not changed. Because gravity depends on the mass of the planet and the size. We have pretty fine evidence of the size has not changed appreciably, and the mass has not change appreciably since very early days in geologic time, as far back as we can go, to when meteorites were falling in making craters 1,000 miles across in the earliest days of the planet. Since then, g is constant.

PAUL GRAY: Yes ma'am?

AUDIENCE: What is the name of your book? We are privileged to be able to watch your TV programs every week, and I am very grateful to be here today. But I think you mentioned that you had written a book?

PHILLIP MORRISON: Yes. We have a book. It's in all the bookstores, especially in Cambridge, perhaps.

AUDIENCE: And what is the name of it?

PHILLIP MORRISON: It's called *The Ring of Truth.* Same name of the program. *Ring of Truth*, published by Random House in their paperback. It's now in paperback. It's a better buy in paperback.

AUDIENCE: Thank you so much.

PHILLIP MORRISON: Thank you.

PAUL GRAY: Phyllis, do you want to show one more slide there?

PHILLIP MORRISON: Oh yes. Very good. This gives you some idea of the generality of points. This was made a week ago here on the campus. So it fits pretty well to ostriches and dinosaurs and all the rest.

PAUL GRAY: Thank you very much.

[APPLAUSE]

There's much concern these days of course about scientific literacy, about the effectiveness of science education, and about the degree or lack of preparedness of young people to understand, to appreciate, to relate to science and scientific issues, quantitative issues. And in so much of that discussion, one gets the sense that folks think that the remedy somehow is that youngsters ought to learn more facts. Well, facts are numbing. They are deadening. And they turn a lot of kids off to science. This presentation illustrated so clearly, so effectively that science is a process, that what matters is the way people think about the questions, the way in which they question authority, as Phil, suggested, the way in which they are skeptics, the way in which they conceptualize new ways of thinking about a set of facts. That's what makes science, and that's the attitude that one hopes to be able to transmit much more effectively to young people in the schools.

Now, before we move to our second presentation this morning, we've been at this a little more than an hour, I'd like to invite you all to stand up and take a stretch. Not leave, please, because it's going to be about 30 seconds only. But if you want to stand up at your seat, take a little stretch before we continue, that'd be super.

Well, stretch break's over. May we continue? Now, many of you are aware that for a decade or so now, MIT has had a football team. And many of you know that a year ago, that team which started 12 years ago I guess, 11 or 12 years ago as club football, that team changed to NCAA division III football competition. It's always puzzled me that that single event has been the greatest source of publicity about MIT since we moved from Boston in 1916.

But we do have a football team. We do have cheerleaders. We do have a marching band. And we do have a homecoming game. And all that proceeds, and it's wonderful. But there is at MIT something which has been called the intellectual or the academic equivalent of the homecoming football game, and it is the 2.70 design contest. It is a rite of passage for all students who take that introductory design course, 2.70. You all have learned the numbers by now from hearing your sons and daughters talk about courses at MIT. It is a rite of passage for all the students who take that introductory design course in mechanical engineering.

It is not just a participatory event, it is a wonderful spectator event. And people line up hours and hours ahead just to get a seat in the largest lecture hall on this campus during the playoffs. Professor Harry West, our second presenter today, is the proprietor of that enterprise. He will describe it, and he and some of his students will demonstrate for you what all the excitement is about.

Harry West is Assistant Professor of Mechanical Engineering. He was appointed to the MIT faculty after receiving his doctorate in mechanical engineering here. Harry did his undergraduate work at Cambridge University, the other Cambridge, and he came to MIT in 1980 as a Kennedy fellow-- one of the tremendously prestigious fellowships which bring the British young people to MIT for graduate study. His research focuses on the design and control of machines to perform useful tasks, and he teaches everything from introductory mechanical design to graduate subjects in kinetics and robotics. He has been faculty advisor to the student group which designs and races solar powered cars from coast to coast, as well as in Europe, and a couple of years ago, 2,000 miles across the Australian desert. He has just the right combination of imagination and spirit to inspire creative and intelligent problem solving in our students, as you will see. It is my pleasure to present to you today Professor Harry West. Harry?

[APPLAUSE]

WEST: Good morning. I'm going to tell you about a course offered by the mechanical engineering department at this university called Introduction to Design. Nobody here calls it Introduction to Design. We call it 2.70. Everything here has a number. I have a number. Your son has a number. 2.70 is a big event on campus. You just heard it described as the homecoming game of MIT. And the winner of the 2.70 contest is like the player who throws the final touchdown in that homecoming game. For many students, their goal in their sophomore year is to be that student who throws that final touchdown. They all want to win the 2.70 contest.

It's a required course for mechanical engineers, but 25% of the class are students from other departments. They take it just for fun. They go through that hell just for fun. It's also a media event. It has an audience on TV of about 12 to 15 million people in this country, and it's even more popular in Japan, where it annually has an audience of about 20 million people. That's about 20% of the population of the country.

Why is it so popular in Japan? Well, the Japanese TV audiences are just amazed at the extraordinary creativity and determination that is shown by our students. In fact, they can't believe that one student working alone can build a machine in that much time and get it to work.

Now, I am going to show you a video of last semester's contest. It's not due to be broadcast on PBS until November 8 at 8:00 PM, channel 2 in the Boston area. But [INAUDIBLE], the PBS production company that has produced the show gave me an advance copy so that I can show you. I'll show that at the end of my presentation.

First, however, I want to tell you about the educational goals of the course. You see, 2.70 is not just a show. It's also an important part of our engineering curriculum, and I don't want you to forget that. The introduction to design course aims to fulfill many goals in our crowded curriculum. The course introduces elements of mechanical design, including mechanical drawing, machine elements, gear ratio optimization, kinematics, principles of bearings, friction equations. We also teach techniques for design and manufacture. We teach techniques for brainstorming, sketching, idea selection.

The course also serves as the introduction, for many students, their first use of machine tools. See, I said it was a crowded curriculum. We do that all in nine hours a week in one semester.

Now for many of our students, this is the first time that they've ever taken a close look at a bearing, or many of those other parts like a differential that make up the vocabulary of a mechanical engineer. You see, the reason students are admitted to the mechanical engineering department at MIT is not because they took apart their mother's car when they were teenagers and put it back together again. Some of them have done that.

Most of them are admitted to this university because they're whizzes at math and physics. That's what they're good at. They're brilliant. But it's quite possible that they don't know the difference between a nut and a bolt, and that would be a disadvantage for a practicing engineer.

Part of our responsibility in this course is to form connections between the engineering science that makes up most of the curriculum here at MIT-- make that connection between the science and real things, real machines, engineering products. We want to motivate the students to show them that the equation that they learned in 201 can mean the difference between a machine breaking or a machine succeeding. It can mean the difference between a customer satisfied or a customer frustrated, the difference between a successful company or chapter 11, or the difference between a growing economy or an economy in decline because of international competition. You see, ultimately, the way nations compete is through the design and manufacture of products. That's how we compete.

Now the course has evolved over the years, and it's continuing to evolve. I suspect it will continue to evolve in the future. Let me tell you about three of the changes that we've made in the last two years. First of all, we've recognized that we have a problem in this country in the area of design and manufacture. You see, in most companies, we have a design department, and we have a manufacturing department. And sometimes they talk to each other, but often they don't. Sometimes the designers throw over the wall a product to the manufacturing department and say, make this. And the manufacturing department says, we can't. So they lob it back over the wall and say, fix it. And the design department tries to fix it. And this is a slow process, but this is how many companies work.

We looked at our curriculum here at MIT, and we found we were doing exactly the same thing. We had a design course, 2.70, and we had a manufacturing course, 286. Now that's wrong. So we couldn't criticize industry-- we do criticize industry-- we couldn't criticize industry without also looking at our own performance and changing that.

We've now reorganized our curriculum. So we have a design and manufacturing course, 2.70, that teaches students how to design and manufacture or fabricate single parts, single products, prototypes, because you have to consider the design and the manufacturing problems at the same time. And we have another course called 286, which teaches students how to design and manufacture a large number of parts. You must change the design if you want to produce a large number of parts. You can't use the same design for one part that you use for 100,000 parts. It doesn't make sense.

So the division is no longer between design and manufacture, but between the lot size. That's how we have changed educational program here, and we believe that this is the direction in which US industry has to move if we are to be competitive with our trading partners.

A second change is that we have put increased emphasis on safety and product liability. With the advent of strict liability, engineers had to take increasing responsibility for the products they design. If a product leads to an injury, then that is the designer's responsibility. Even if that part had not been used in a way that the designer had foreseen, even if the part had been misused, it's still the designer's responsibility. So we're spending more of our time teaching students about human factors, and about understanding how people interact with machines.

And thirdly, we have introduced more material on ethical and social issues. You see, we don't want our students just to design products. Of course, we hope they design good products. But we also want them to be the ones who make the decision as to what product should be designed. And if that is to be the case, the students must be aware of the financial issues involved, and also the ethical and social issues involved.

It's important that students understand that a product is not just a piece of technology. It also has an impact on society. Some of the issues we've looked at recently are the design of products to serve an older population. With our changing demographics, we're having an increasing percentage of older people in our society, and they have particular needs which must be met. We have looked at the design of a non-reusable syringe, for example. Obviously, that's motivated by the AIDS problem. And we've looked at design problems in the treatment of waste. We live in a society which produces a lot of waste, and it's got to go someplace. And ultimately, it's engineers who are going to have to fix that problem.

However, above all of this, the emphasis in this course is on creativity. That's at the heart of the course, and we haven't lost that. I hope we can continue to add to that. Our goal is to show the students how to be creative. We want to motivate the students, and we want to encourage them to feel confident as designers. And there's nothing more creative than the 2.70 contest.

Let me explain a little bit about the 2.70 contest. The 2.70 contest is just the last half of this course. It's the second project, and it's a design and build assignment. Each student designs and builds a machine to perform a simple task. To do this, we give the students a kit. Let me show you a kit. I'm going to have to talk loud. Thanks. OK. Can you hear me? Yes? Can you hear me now? Can you hear me now?

PHYLLIS MORRISON: Testing.

WEST: Oh, this is much better. Thank you. OK, that's clearer, I can tell. What we do is we give the students what they call the box of junk. It comes like this, and it's full of junk that's donated by companies from all over the United States, and indeed, some from Japan now. This is given by Julius Coach Company. This is given by Mattel. Bits of aluminum from Alcoa.

It's not just junk, actually. It's carefully selected junk. There's some real engineering materials here. Some pieces of aluminum, some aluminum square tubing, some flat aluminum sheet. There's also some rather nice DC motors. This is a geared motor. This here is the motor, and in here, there's a gear box. I think it's got about 100 to 1 gear ratio, so it's not that drivable. We give them two of those.

This here is another gear motor-- a smaller motor, but a higher gear ratio. Actually, this is part of a Polaroid camera. It's what makes your Spectra load its film, and pieces of wire, elastic bands. We also give them some extraordinary things, like this. I don't know what this is. Ah, so a great worry to the students.

You see, initially, they think it's just a question of putting these bits together. That's not the case. They ask me, where does this go, Professor West? No idea. This is not a kit in the sense that they know how to put it together. This is just like a warehouse of parts. There's far too many parts here for anybody to use all of them. And the first lesson you have to learn is what is useful. What do you really want to use?

Polaroid sunglasses lenses. All manner of parts, including a Band-Aid. This is the one part of the kit they're specifically instructed not to use and to never have any need to use.

OK. So we give the students all these parts, and we give them a very well-defined problem, and some rules to go with that problem. And then we say, go to it. In six weeks' time, you must have a machine that works, and it's going to compete in the single elimination contest in front of your peers. There's going to be 1,000 people watching you in that room, and you're going to have to stand there behind that joystick and make your machine work.

Now, you can imagine, that's a very stressful assignment. But we also allow them to fail. And I think this is a very important part of the course, is we say, you must put your machine on the table, but your grade has nothing whatsoever to do with how well this machine works. The contest is not an evaluation of your design ability. It's a celebration of the fact that you've finished. It doesn't matter if it doesn't work. It's good if it does. We like it if the machines do work. But that ultimately doesn't matter. What we want you to do is to put that machine on the table.

And here I have a couple of machines that students have built. Now, they're kind of stylized engineering problems. In some ways, maybe they're too simple. But I think it's important to remember that this machine is totally original. Nobody told John Gilbert how to build his machine. He did it by himself. How often does a student get an opportunity to build something totally original?

It's [? kind of funny. ?] You'll see it work in the video. It didn't win the contest.

This is the machine that won. Aaron Flores built this one. And it's very simple. And Aaron is a student who learned one of the important lessons in the course, which is that when you design something, you must consider how it is you're going to manufacture that part. Because if you've designed it and you can't make it, it's not a good design. You'll see in the video many machines that are great on paper, great concepts, but the students couldn't build them. In many ways, those students have learned more from this course then the students who do build the winning machine, because one learns from one's mistakes.

What I'm going to do is I'm going to go through a few slides to give you a little bit of background to the course and to the nature of the contest, and then we'll run through the video. The video itself doesn't explain the rules well enough for my liking, so I want to do this first. Here we go.

Here's the tide of the contest this year. It was called, "Not in My Backyard," and it's about the "Not in my Backyard" problem. The "Not in my Backyard" problem, or the NIMBY problem-- OK. Again, the "Not in my Backyard" problem, or NIMBY problem, is a very important technological and social and political issue. Because we all create trash, but none of us wants to live next door to a trash dump. We all consume electricity, but none of us wants to live next door to a power station. Every one of you here has got a student at MIT, but would you want to live next door to a fraternity?

[LAUGHTER]

This is what we mean by the "Not in my Backyard Problem." Yes, we need it, but not in my backyard. And the United States is facing a crisis of "Not in my Backyard" problems, because we have waste, and nobody wants it. And we have empowered people not to accept it. There used to be a time when society imposed waste sites on poorer communities. Well, we have now empowered those poorer communities to sue and to stop that incinerator being built in their city, their town, their county. And as a result, waste sites are not being built.

Well, these are challenging problems, and they're going to have to be solved by engineers working together with the community, with politicians, and with lawyers. The irony of this course is to drive home the point, both faculty and to students, that whatever the solution to the NIMBY problem, it's not that the strongest or the fastest, nor even the ones with the best lawyers that should win. These problems have to be solved fairly and equitably in a way that all parties feel that they have been treated fairly.

Anyway, enough of this politics. Let's get to the nature of this contest. There's a waste can. It's six inches in diameter, seven inches high, and there's a ditch. On the other side of the ditch, there's you and your opponent. You've got to get that can out of your half of the territory into his territory, out of your backyard into his backyard.

There's a starting area, 12 inches square, and you can build any machine out of that kit 12 inches cubed to compete. You have 30 seconds to complete. The winner at the end of 30 seconds is the one with a can not in his half of the playing field.

OK. Next time, try recycling. This is the kid of junk the students get. And when they look inside, they do indeed see junk, and then the good ones sort out the junk from the useful engineering material. And they find that there is a lot of very useful engineering material here that is donated by about 30 different companies.

There's lots of rules. There's fine print to go with this, and there's more fine print. But then the design process starts. And we encourage the students to take a notebook with them, and they must sketch in their notebook their designs as they come to them. And they must explain to their instructor why it is that their design is good, what it is about their design that is going to make it succeed. Ultimately, they will be graded not on how their machine does in the contest, but on the quality of their notebook.

The students also learn how to machine. Many of the students have never touched a machine tool. This is a drill press here. They've never touched a drill press. We could give them a technical course on drill presses, but that would not be interesting. That would be beneath, I think, the interest level of our students. But you give an assignment, they've got to build something, and they've got to use drill press to build it, they learn how to use that drill press really quickly. And they get technical help from technicians and from faculty. It's a very intense process, with faculty working down in the lab about 12 hours a day sometimes.

And then the contest arrives. Now, the judging of the contest, we subcontract to judges who wear these black and white shirts. And they check the machines to make sure that their machine has followed all the rules and satisfied all that fine print. Then the contest starts. You put the machine on the table. I say ready, set, go, and then you're off. And one of you has to lose. It's kind of harsh. Sometimes it's very unclear who the winner is. But whatever happens, the audience really enjoys it, and so does the media. The TV crews surrounding it, we get TV crews from all over the world who want to attend.

And then at the end, there's a winner. Aaron Flores this time, who is very pleased with himself. And he's been interviewed by many different TV companies as a result. I guess it's going to change his life. Could we show the video now, and then I'll answer questions about the course.

[VIDEO PLAYBACK]

-It wasn't so long ago you could lift the hood of a car and figure out for yourself why it wouldn't go. Now, even a highly trained mechanic like Steve here needs a computer to help tell him what's wrong. The more machines do for us, the more complex they get. These cars drive better and use less fuel and pollute less than they used to. Tomorrow's machines will be even more sophisticated, and their designers, the mechanical engineers of tomorrow, will need firsthand experience in just how balky a complicated machine can be.

Time again for the annual design engineering contest at the Massachusetts Institute of Technology, where students learn the joys and pitfalls of creating a machine. This year's challenge, a game of "Not in my Backyard" played on this oval table. The object? Get this trash can out of your half of the field. The two contestants in each round have 30 seconds to reach the can, coping with the ditch on the way, and get it into the opponent's territory.

The contest began six weeks ago, when the students, 200 of them in the design engineering class, were each given an identical kit of odds and ends.

-This is the kit. What have we got here? A square aluminum tube, a wheel, a constant force spring. You can extend it, and it will close very quickly. We have this interesting looking motor, and I think it's used to drive part of a camera, originally. A music box. Well, I have no idea what this is going to be used for, but I'm sure it will come in handy.

-This is the stuff engineering dreams are made of, and concepts for the dream machines are ambitious. On paper, anything is possible. Everyone has a strategy.

-So is everyone thinking about a car?

-You can only do several things with a car. You can either go around, which is kind of ridiculous because you've got to steer it. You can go over, but if you get in the ditch, then you're stuck, or you have to have something that can go completely over the ditch. And then you have to torque it down so slow that--

-So what do you have in mind?

-An arm.

[INTERPOSING VOICES]

-But what if the car is more maneuverable? You can adjust to any situation with a car.

-Ah, but if you have a maneuverable arm--

-At this early stage, talk is cheap, and helpful.

-Is your arm going to be able to move along the table?

-Mhm.

-Okay. Here we go. What if I draw my bridge has a barricade on it so you can't push it away? Then what are you going to?

-Hold the can over the bridge.

-OK.

-It's a lot of fun. It's something-- you don't really realize you're in a class when you're through the whole thing, because you're just talking about ideas, putting things together, and just getting familiar with the entire design process.

-It's in the shop that ideas must become reality, where paper concepts become working parts, grasping claws to seize the can. Lazy tongs to snatch it. Ideas take shape-- some simple, some complex.

-It's going to be run by a motor down here extending from the motor through a bar here and to this. So as the motor winds up, it's gonna pull the link forward and extend on the other side. And it's gonna drive off the end and get to the can first, hopefully.

-The weeks pass like a song. And troublesome details start to pop up.

-Ow. One more time.

-It is exacting work. It calls for a skilled hand and eye. It takes precision manufacturing to build reliable parts like pulley systems, triggers, and gearboxes.

-It seems so easy on paper, and then there are things I forgot to account for. Who would think that is was going to be so hard to mesh these things. But it just takes hours longer than you thought it would.

-With concepts reshaped to fit reality, testing begins to zero in on any major flaws. Some are having more success. Troy's strategy is a bridge to cross the ditch. Like the others, he's learning fast.

-Most of my engineering experience has been on paper, pencil-paper equations and stuff. And this is the first chance that I've ever had to build something concrete and actually see what all this education is supposed to have taught me.

-The bridge is nudged into place. The car drives across. Simple, but apparently effective.

-I thought of a lot more complicated things to do than this, but I thought that this would work. And it was really simple.

-Another strategy is not to cross the ditch, but to drive around it. Aaron has opted for this approach, which calls for speed and accuracy. Others are aiming to beat the fast cars to the can by reaching across the ditch with an arm, while still others plot ways to beat the arm.

-A lot of the arms depend on getting to the can first. So I wanted something to move the can so that the arms wouldn't be able to get a hold of it. And that's what the projectile launcher is for here.

-What is faster than a grasping arm?

-Go!

-Projectiles, bridges, arms, cranes, cars, tractors, all are ready on the big night for the head-to-head competition, getting the can into the opponent's territory.

-Are you ready? Set, go.

-It's Troy's first round. The bridge does it's job, but will Troy's driving skills survive the pressure and excitement of the cheering crowd? Finally, he makes it. The head-to-head playoffs continue. Bill's bridge is up, but his car is down. Another engineer learns a hard but valuable lesson.

-When I came in here, I was like, you can do almost anything you want. And then when you start building, you begin to figure out that you can't do anything you want, and it gets really difficult to make your ideas become a practicality.

-Bridges are proving a popular shortcut to the can. But when you get there, it's shoving power that counts. And Spud's vehicle, with its large wheels and rubber caterpillar treads, proves to be one of the real muscle machines of the night, pulling both can and his opponent across the line to victory. But a bridge-car combination is no match for this arm.

Katie has used a magnet to catch the can. The powerful gears from the music box wrenched the can out of danger. The easily controlled arm crane brilliantly solves the drive-ability problem.

-I'm glad the machine doesn't take much to control it because when you're up here, maneuvering the joystick, it's pretty crazy.

-Meanwhile John's projectile is merciless for the other fast arms, buying time for his slow but reliable tractor to make its way to the can. Aaron's fast car is also moving up. He goes the long way around to the can, but his speed and unerring accuracy win contest after contest. One by one, arms are losing to vehicles. The speed of the arms is no match for the power of the cars. But at least with an arm, you can vent your frustration. And now, the last arm in the contest is in trouble. The crane arm hit the can so hard last time, the magnetic capture device broke. A hasty repair, with no guarantee attached.

The fourth round. Katie fires perfectly, but the magnet dangles uselessly from the broken can grabber. An elegant concept too delicate for the rigors of competition. Troy's bridge is flawless each time out. It's still the driving that's giving him problems.

-I couldn't get over my bridge. That was the main problem. I only had less than an inch of clearance on either side. I just couldn't make it. Maybe I was nervous. I don't know. I just can't drive.

-Aaron seems to have no problem driving his car, and it's time to reveal his secret. Watch from the slow motion overhead camera as he simply drives straight ahead, letting the rim of the track guide the car around the curve--brutally effective. Two rounds to go, and speed meets power. Aaron's car runs away with the can as usual, but wait. Spud's muscle machine simply plows relentlessly on for the comeback of the night.

The audience chants for a rare double win. If the judges let Aaron through despite his loss, the night's outcome could be altered. But good engineering is rewarded. A double win. Both move on. John's projectile machine was designed to beat arms. But now the arms are gone, and he's up against Spud's muscle. The projectile is not much use now, and it threatens to be simply a down and dirty shoving match. But John slips away into the ditch, taking the can with him. This time, Spud's been outmaneuvered. John's ditch strategy was part of a carefully thought-out contingency plan.

-If I have to go into the ditch, this machine is capable of driving out backwards. So I can go in and out of the ditch. And if need be, that could be very advantageous.

-The semi-finals. It's John's bridge tractor projectile combination versus Aaron's self-steering speed demon. The projectile hits the can first, but Aaron sweeps it away. Now, John's ditch strategy is his last ditch hope. He backs away, planning to climb out from the far end. But then, John's machine topples, done in by the ditch.

In the other semi-final, the bridge gives the red machine a fast start. But while strong, it's clumsy, at least up against the maneuverability of the blue racer. With one wheel in the ditch, the red car's in trouble. And so it's on to the finals, where Aaron's self-steering speedster will clash with the nimble blue hood, in for one last pit stop.

-Ready, set, go!

-It's no contest in the race for the can. Now, Aaron has to hold on to it while the blue car goes for the steal. But a fatal slip, and it's all over except the shouting.

-I built it for the job. I didn't build it for looks or anything. So I finished. It was a really simple design, and it was really fast. It was the fastest one, so I won.

-Victory is sweet, but all the students now share a taste for design that no classroom can match.

-It's too bad that engineering is so textbook, and that a lot of people don't get this experience until they're out in the workforce. And then everybody's wondering why we're losing our edge in manufacturing, and this is why. It's because they don't have any experience in doing things like this.

[END PLAYBACK]

WEST: Do you have any questions? Yeah?

AUDIENCE: Could you in your class, or do you in your class counsel your students about how to keep a proper notebook so that their ideas can be patented someday?

WEST: Absolutely. The question is, do we, in our class, tell the students how to keep a proper notebook so that if they come up with a patentable idea, a better mousetrap, then it can be patented and they will maintain rights to it? Yes, we do. Not only that, we've got special permission from MIT which eliminates any ambiguity as to who owns that idea, and it is the MIT student who owns it. MIT as an institute has given up all rights to ideas developed by 270 students, which is good. Sometimes at the graduate level, there is some misunderstanding on that problem. Yes, we do.

And let me also bring up another point. I don't. I'm the coordinator for this course, but there is a total of about 16 faculty who teach it. The students are not taught as a group of 250. They are taught as small groups of 16. And it's in those small groups that they're given individual advice in both how to build machines, how to document their work, and how to protect their rights. Yes sir?

AUDIENCE: You have a course 2.70, 2.80. I'd like to come help with a course 400 so that the engineers are out into the field seeing how an automobile or a some other item can be repaired before an emergency. Such as, say you're out up in Vermont on the weekend, you have a new car. It's Sunday night, at 5 o' clock. You pull in the gas station. We're ready to go home. He says, you'll have to come back tomorrow. How does the boy try and help himself? The cars are so complicated, mechanics can't even fix it.

WEST: Are you speaking from personal experience here?

[LAUGHTER]

You're right. There's a lot that we should be--

AUDIENCE: [INAUDIBLE] so someone can help themselves in an emergency just to get home or get to a place where they can get help.

WEST: You're right. There's a lot that we should be teaching our students. However, we only have a limited amount of time, and we are trying to reduce the stress level on them. So we have to pick and choose what we teach. And right now, we think that what is most important is to teach them some of the elements of mechanical engineering design, and to teach them to be creative.

The way we teach them to be creative at MIT is we assign it. We say, be creative. You've got six weeks. And we find that works. It's a very stressful time for them, but it works. We all have a book within us, I'm told. We are all a creative people. But being creative is a very painful process, and you need somebody to kick you to make you creative. And that's what we do.

Now, if we were to put more material into the course, we would reduce the level of creativity that we could have in the course. So we've made a decision not to teach students everything. We can't teach students everything. But we teach them where to go to learn more material. So while we don't teach them how to fix your car, I would hope that by the time they graduate, they'd know the steps they would have to go through the look up that information.

Yes sir?

AUDIENCE: How do you make sure that the work is not the work of an outside consultant? [INAUDIBLE].

WEST: Good question. The question was, how do we make sure that the students are coming up with their designs by themselves, not going to outside help? Well, I guess a good engineer is always willing to go to outside help. Most students don't. I guess it is possible that some do get help. I asked my students why it is that they don't cheat. They don't want to.

You see, they're not competing with each other by the time this contest comes around. They're competing with themselves. It's not a question of winning the contest by the end. It's a question of just beating that machine that they've been struggling over for six weeks, and they wouldn't want help from outside. Sometimes they don't even want my help or help from other instructors. They're so determined to do it by themselves.

I just received a request. If you have any questions to answer, if you could go to the microphones, that would help. Yes sir?

AUDIENCE: You very beautifully stated the ethical and social concerns in your talk. Were you concerned about the message "Not in my Backyard" gave as antithetical to that?

WEST: Yes, I was. And it's my fault. You see, I'm English, and in England, we use a lot of irony.

[APPLAUSE]

And one lesson I have learned is that irony is not as well received throughout the world.