PRESENTER: We meet this afternoon on behalf of the faculty of MIT to honor two individuals of whom we're very proud, and one of those is the individual for whom the lecture carries his name, Dr. Jim Killian, who once again honors us with his presence here today. The faculty, in 1971, established this lecture series in tribute to Dr. Killian and his concern for the excellence of MIT. I was thinking, as I was [INAUDIBLE] today, that all of us who teach [INAUDIBLE] often have that feeling that freshman are getting younger each year.

And I was wondering if Jim feels the chairmen of the faculty getting younger each year because I was certainly a young sprout when he relinquished the ranks of the Institute and became chairman of the Corporation. [INAUDIBLE] I think many of us who have memories of growing up during that period have quite an appreciation for the affects that he had on the Institute and the way it is today, and I would just like to say, I hope, Jim, that we are still living up to some of your ideals for this place. And we appreciate very much all that you have done and continue to do, and we're awfully glad you can be here today.

I hope you're all ready to begin your homework assignments, the little red books, because this will give you all the facts about both the awards and the speaker today. And I'm not going to repeat any of those. I do have the [INAUDIBLE] to present the Philip Morrison tangible award of this. He already received the more tangible part, the check, some time ago. [? And to ?] the interest of that, today, I would like to present the scroll, which let me quote the end of it. "In recognition of his contributions to many fields of physics, especially astrophysics, through his long and distinguished career, his originality and productive insights have inspired and delighted professional colleagues, generations of students, and countless followers of his stimulating and [INAUDIBLE] reviews of science and technology for general audiences." So, Philip, you want to add this to your collection of good things.

MORRISON: Thank you very much.

[APPLAUSE]

PRESENTER: If I can take one more minute of your time, I'd just like to comment. One of the things that I said to my class today is there are events at MIT which happen rarely, and you should be pleased to be here when they happen. Don't miss them. I think there's going to be one this afternoon, and I'm sure we will find that true at the end. The other thing I wanted to comment was that in inviting people to come, those letters went out over my signature, and many people who couldn't be here today replied.

One of Phil's former students replied, and I wanted to quote to you a couple sentences from that because I think it's important. At least, [? I wanted to do it, ?] all right? I will share the whole letter with Phil later, and he hasn't seen these. But these are just two sentences that struck me as the kind of tribute that any of us would certainly be more than proud to have, referring to lunches that they used to have at the [INAUDIBLE] Physics Department.

"Phil's comments served to cajole, provoke, and enliven the group, and I feel certain that most of us who attended those discussions extracted more from our own minds than we possibly could have in any other way," which sounds to me like the best description of a teacher I've heard recently. And the other is, "the quality that I admire most in Phil is his tenacious affection for the world in the face of all its imperfections. Phil's life is a testimony as much to the spirit as to the human intellect. By honoring him, the faculty members of the Institute do themselves proud." And I agree with that, [INAUDIBLE].

[APPLAUSE]

MORRISON: Thank you very much. It's obviously a moving occasion and, indeed, an honor, one bestowed by so many predecessors, teachers, colleagues, and students, many people being more than one of those categories at the same time. So I'm properly moved, and I should like to, however, come to the matter at hand, since it is not only a ceremonial occasion, but one of great interest. The metaphor that will perhaps run the entire show this week and next week is something about science as a tree, as a living, burgeoning tree, very complex, very difficult in many ways, very protean, with many sides, fruit of good and bad.

Next week on the 10th, I shall try and describe, in primarily scientific language, one of the principal fruits of the current branches of astronomy, the marvelous story we can now tell with great incompleteness about the nature of the galactic world that we see. We can still tell quite a lot, but it's still far from complete. Today, however, I want to look at the tree in a much lighter context. I realize that we'll try to discuss one of the very important fruits [? of the ?] methods [? of your work ?] in the vexing domain of cosmology, the study of the universe as a whole, and I hope to show something with no formulae and very few graphs to give some idea of the logical structure and the tantalizing-- I would say, paradoxical-- conclusions to which we have been very reluctantly drawn in recent considerations, largely [INAUDIBLE].

And the genetics of the tree, how can it grow after all, which, of course, is a statement about the future, the future of our society, of our species, because it is young people who represent. However worthy the old folks are who get awards, it's the young people who represent science as it is coming, not as it has been. So that's what I want to talk about, and I've divided the talk into three pieces.

And I was moved somehow in the last few days, thinking about the very recent death of my old graduate school friend and colleague for many years, Frank Oppenheimer, himself, in the last 22 years, one of the most distinguished contributors to the worldwide solution to the problems of the proper education in science. He had on his wall always, in the office in the last few years in San Francisco, a quotation which I was not clever enough to memorize, but I can paraphrase. Very bad for poetry, the paraphrasing, but what can I do?

It's a winning remark by [INAUDIBLE], who spend much time in that museum, and it describes-- some of you will have read it. It describes her perception of some scene on the coast of Maine when she was at the beach and saw the bay studded with islands, characteristic stacks of whatever on the coast of Maine. And she said of the islands, she said, they appear so distinct, but in fact, they are connected underneath. The Mainers think they are as separate as themselves, and I leave you to conclude whether the Mainers, in fact, are as separate as they think. [INAUDIBLE].

So I'm going to talk three hours for the speech today. I hope they are, in fact, connected underneath. And I'll ask you to indulge in the somewhat clear change in pace because I do believe they all go towards a common end. So I shall go to it.

Now, I guess we first need the lights off, and I'll try the first slide. Yes, an admirable slide. [INAUDIBLE] That's swell. I'm showing this slide here, many will recognize. It is done by the wonderful drafstman's hand of a famous [INAUDIBLE] architectural critic and scholar.

Apparently, nobody knows whether [INAUDIBLE] really built any buildings, but he sure wrote books and drew pictures about building buildings. He was one of the great figures of whom we know in the 12th century when the name of the architect was not yet printed on the building. So there he is, and this is a picture from his drawings, which has come down to us, a very handsome parchment book with his own inscriptions in a beautiful hand in old French, of course. And up here, what you see is a marvellous machine.

It goes without saying. He never built that machine, but he could certainly draw it. [INAUDIBLE], and he says in here, this machine, if properly built, will go forever.

[LAUGHTER]

It's constantly unbalanced, as anybody can see, or speaking more precisely, the center of the form is not the center of mass. And, obviously, it goes around and around with a [INAUDIBLE] that's given by the [? designed amounts, ?] I expect. And here, a later hand has written, [LATIN]. I say, amen. And he didn't build it, either.

Well, this is only to show that understanding of perpetual motion and energy is an old tradition, and people had a great deal to think about it for a very long time. I am anxious to point out. It's not widely recognized, but I think it is conveniently well documented. It's [INAUDIBLE] discussed by Joseph [INAUDIBLE] in the first volume of his famous work on science and civilization in China that long ago, before there was an MIT, long, long before that, and before there were the memes that we all know in which mechanical systems do our bidding one way or another, there was a strange feeling about mechanisms because in those days, motion was regarded as being of two kinds, [INAUDIBLE] be seen in the philosopher's [INAUDIBLE].

One kind was animate motion. People and flies and rabbits all have an animate motion, volitional and so on, and that was clear in men who recognized that life meant motion. And the second thing were those other, inanimate movers that were movers of their natural selves-- the waves, the wind, the smoke rising. No question, that was nobody made it move. It just moved. It was inherent in the system so to move.

And that was all that moved, and then, beginning probably not much before in terms we know about, [? holistic ?] times, there were the engineers, mechanicians, who made clockwork and hydraulic [INAUDIBLE], gear generally, which moved also. Now, when that happened, that was not considered a commonplace, as today it is. Nobody is interested and has any philosophical pleasures, really, in watching a mechanical toy.

Nobody ruminates and does big metaphysics on this motion, just like that of life, or like that of the wind, but is neither. It's actually quite marvellous. And in those days, however, yes, mechanicians, like alchemists and conjurers, were people who had some kind of magic, to make motion come out of the inanimate without invoking the great forces of nature. It was not in nature that a few wooden and brass pieces would move, and yet they do.

So this was the sign of something elementary and new coming into the world, and I really have to say that I think we see today very much the same attitudes and very much the same discussion and very much the same phenomenon happening, not in the domain of locomotion, but in the domain of rational processes. Let me say, to be very metaphorical, thought. And the word has been coined, AI, to describe something which I guess would have been called under the Greeks, AM. Then I would imagine the same objections and so on. Now, I want to say, the same objections and the same failings, because the fact of the matter is when you did have a little mechanical mouse that moved, it didn't help you much understanding mice.

[LAUGHTER]

[INAUDIBLE] the great mechanical system, and now I will go ahead because I want to end up in the 1980s perpetual motion, which still exists, at least in Southern California. The next slide will bridge a gap.

This was a figure to naive to describe, a 17th-century [? application, ?] and I encourage hydrodynamic students to analyze it carefully. And, finally, a more modern one, having the characteristic Victorian air. Next, oh, it's mine to do that.

Here, you see [INAUDIBLE] is water filled, and this is air filled. So you get air. So, of course, the balls [? do not ?] rise and sink, and evidently a very good machine would [INAUDIBLE] 1865. And I'm calling your attention to one extremely interesting part of this machinery we have reason to talk about a lot.

It's remarkably invariant to moving one ball. You can just move them along, and each time you move it, you get back to the same position. It's made of [? beans, ?] all of which are identical, and if I just move it up one and over, [? it would not move up. ?]

And the great part about this machine is that it's periodic. It's wonderfully periodic in its structure. So either it moves, if it's the solution to the [? periodic ?] structure, or it doesn't move. And I think you've made your choice. [INAUDIBLE] is not changing. Whatever it does, [INAUDIBLE].

[LAUGHTER]

The concept of energy, which is, of course, a major accomplishment of our 19th-century forebearers, now enormously elaborated and given strength in our time, is a powerful headline concept today, and I don't think even the bad context-- I believe [INAUDIBLE] a deeper understanding but in a reasonable context. That's to say energy has now been translated, for a reasonable, economic interpretation to be given for that, into a discussion not of the abstract quantity that remains invariably in changing systems, but of something which I could call food or fuel. Energy really means that. It means what some fundamentalists have tried to call [? variant ?] energy or even something close to free energy, not quite, but something rather like that.

And everyone treats it that way and treats the frugality. You've got to conserve energy, they tell you, as if that were not written long ago, but, of course, they mean something quite different. On the other hand, there has surrounded this a powerful, religious myth, a myth to which everyone will always attach the wonderful formula, e equals mc squared, that I needn't bother to write, which has really very little to do with any of the consequences that allegedly came from it and really is very poorly described. [INAUDIBLE] spend a lot of time writing about cognate matters.

I want to tell a little story about this because [? I don't know how it is, ?] but it brings out what I [? really am ?] talking about [INAUDIBLE] education. This is not a gothic tale, not even an 1865 tale, not even a 1910 tale. It's a tale [? which ?] followed the problems of the *Wall Street Journal, Forbes, Newsweek* and the *New York Times* from 1976 when they first burst until 1981, after which the papers have fallen into silence.

It's a Southern California story, and it deals with [INAUDIBLE], not important to discuss this man, [INAUDIBLE] inventor, actually, a firm and able inventor with many patent [? skills credit ?] who lives in [INAUDIBLE] Hills at the lower, southwestern corner of the city of Los Angeles, very nice surroundings, and in 1975 began to [? bring ?] about in the bigger fiscal circles of Southern California, from Irvine to Anaheim and around, that he had invented a machine which was not exactly perpetual motion, but it did succeed in producing a limited supply of available energy out of tap water. And this machine [INAUDIBLE] as he says later [INAUDIBLE]. And the machine, a photograph appears in the *New York Times* from about 1977, a stainless steel object, about the size of an ordinary trunk when we had trunks, quite a big machine, buttressed with many gauges and levers and a jet on the back of it and a few hose connections.

And when the lucky investor was given a demonstration, the tap water was put into the hose connections. A little [? extra ?] work was done to start it off. It was always naturally granted a little starting energy, and then after a short time, a blue flame, two feet high, came out of the jet, being the hydrogen-oxygen combustion from the water, and lasted for as long as you were patient or up to 20 minutes, whichever came first. Now, this thing, it was rather impressive. It caused a considerable stir in the sort of isolated financial markets in Southern California, and a certain company called the Preston Corporation, which had been a housing company, you know, housing development and real estate company, was not doing well because in the mid '70s construction was at a minimum.

They looked around for something else other to invest in. They found Mr. [INAUDIBLE] wonderful machine. And without any public statement, their stock rose from about $3 to about $25 in the course of three or four months because they acquired the rights to this machine, not to the machine, per se, but to the use of this machine in the heating of homes. [INAUDIBLE], very interesting device.

Well, then, the story reached the *New York Times.* I think it was a little earlier than the *Wall Street Journal*, which, *New York Times,* only six months after that with this picture and description and all the rest. And by that time, the attention of the Securities Exchange Commission had been drawn to this ingenious investment, and certain professors had issued statements which I could not word any better myself, saying, this machine is not going to work.

In spite of the testimony, there were quite a few authenticated experts. One of them was a man who had made a considerable fortune in the rental car industry, and he certified that it was a breakthrough of titanic proportions. [? Then, ?] this offer was made by the company through an advisor, [INAUDIBLE] officer, an advisor to Senator [? Voegler, ?] in which they offered to give the government the rights to use this machine for national defense purposes, free, as a contribution to the public good.

And the senator's advisor, not the senator, said that it was, indeed, a very important decision, a very, very happy decision. The SEC was not much moved by this, and by August, the SEC required, in lieu of prosecution, statements by the company that perhaps these claims were not yet valid. And in the upshot, the inventor bought back the rights for about the sum he had paid for it, but he did not give up.

The next year, another story appears. It's still another jazzy-sounding firm in Southern California, saying that they [INAUDIBLE]. They looked into the box and searched it. And they were afraid that they'd find a monkey in the box, but there is no monkey in that box.

And that's the statement. Their stock, too, grows. University of Oregon, and here, I think they've been dragged in a little bit unfairly. I've never read their statements in an old newspaper, so I don't wish to make an attack upon them. But some advisor to inventors, some institutional advisor to certified inventors, looked at various inventors' patents and so on, and who knew they were valid and they might [INAUDIBLE].

I don't think they were talking quite about the same things, because, indeed, he did have issues within several patents about the use of manufactured hydrogen peroxide and various substances, quite a few things touching up on energy and water, but not quite [INAUDIBLE] But this remarkable thing is that by '81, still full of energy after everyone else has abandoned it, after he's paid a lot of money to settle the claims that otherwise [INAUDIBLE] put against him. After the long suits against the Preston Company and [? recovery ?] by many stock holders, I dare say not all.

He issued an interview with the *New York Times* in the little [? reprise ?] section they have every once in a while, saying [? to anyone, ?] I'm still working on it. I am now [INAUDIBLE]. I think [INAUDIBLE] 8 to 10 miles to the gallon in my little [INAUDIBLE] [? Horizon ?] once I get the bugs worked out of it. So [INAUDIBLE] optimist.

Now, I want to mention two things. And I'm very [? centered ?] about this story because [INAUDIBLE] story-- first, the remarkable language in which, at least, again, not a quotation but just a story [INAUDIBLE] of the *New York Times* reporter, very enthusiastic, by the way, [INAUDIBLE] the [? availability of a ?] cheap source of hydrogen had immense implications for the world economy, not only for the use of the substance for gasoline, but also for home heating fuels and other energy sources-- perfectly true conclusion, perfectly irrelevant to the issue when you take it out of water. So what did the inventor say?

He said he uses a laser-like device to generate UV radiation. [INAUDIBLE] splits the steam into oxygen and hydrogen. It then utilizes the electrostatic forces that normally bind the electrons and protons in water vapor to maintain the reaction. These are [INAUDIBLE] energy, first defined by Neils Bohr in 1922, it says. [INAUDIBLE] energy [INAUDIBLE] in the way described is likely to provoke [? the initial ?] skepticism of other scientists.

Then he says, and the action starts with an input of electrical energy from outside the system. [INAUDIBLE], fair enough. This [? will actually convert ?] [? using optical ?] [INAUDIBLE] and other components into large amounts of UV radiation at a special wavelength, precisely tailored to ionize hydrogen and oxygen molecules. The steam [INAUDIBLE] to the reaction chamber, fine. The chamber is [INAUDIBLE] radiation, fine.

During the ionization, electrons are momentarily liberated from the atoms of molecules. Microseconds later, they are recaptured and recombined with a proton in the nucleus of the atom. At this point, the [INAUDIBLE] required to ionize it reappears and then [? gets ?] away. Radiation ionizes another molecule.

[INAUDIBLE] chain reaction [INAUDIBLE] millions and millions of molecules and atoms. Now, you notice all the elements. It works on a micro scale, like nuclear energy, so we can't expect to see whizzing gears and balls filling with water. It works because electrostatic energy-- in fact, it says, extranuclear, something like, but not quite the same, as nuclear energy.

And it makes a chain reaction. Now, all of these features precisely describe the way in which most people, not involved, would have to regard the reports of nuclear energy. [? When they are made, ?] of course, [INAUDIBLE], and that's all too certain.

The trouble is the essential point of the release of energy, say, from the nucleus, or, say, from the water or anything else, has been missed, and I blame myself as much as the rest of my [INAUDIBLE] who had not really thought clearly of trying to make clear what is the essential feature of energy release. And, of course, it is plain. I've already indicated it.

It is not chain reactions. It is not inside the nucleus or inside the atom. It has not a thing to do with those things. It has to do with the change from initial to final state-- no change, no energy release-- and the only exceptions are absolute changes, changes which we [? cannot quantify ?] absolutely, such as orientation, [INAUDIBLE] through time, and change of position. That's about all you can find in the world that will change and not release energy. Everything else, every other change for [INAUDIBLE] is shaping the position of two attracting or repelling substances, almost every other change [INAUDIBLE].

But the important thing is the change. When the uranium goes in, what comes out is not more uranium. Even [INAUDIBLE] reactor, you get more fuel out that isn't the same, that has very substantial change not present in the balls that you saw going through the water, not present in [INAUDIBLE] machine, but present in every authentic way to release energy. And I'm afraid we've somewhat missed that. Most people don't recognize that that is a significant thing.

It is energy that makes things work. Energy store can be anywhere. In the micro world, it can be concealed, and, of course, a new person might find a way to release energy, just as a new person, 40 years ago, found a way to release nuclear energy. So it's much the same thing, and I'm not claiming that we have a way to change [INAUDIBLE] to [INAUDIBLE]. But I argue that this is the type of problem which I believe we must direct attention to if we are to solve the problem of a general public [INAUDIBLE] into science.

There is, of course, an old precedent for this, the bush burned who was not consumed-- a clearly miraculous act. So it says in the good book. So I can [INAUDIBLE] support for this proposition.

Now, what I'm going to talk about for the next 30 minutes [INAUDIBLE] is to expose a little bit and try to follow the logic of what I think is the most remarkable of all the extensions of the idea of energy that we have yet encountered, an extension which, I have to admit, I don't absolutely, fully understand. And I think I'm not alone in this. The importance of [INAUDIBLE] should be fully confirmed, and it is strongly and largely [INAUDIBLE] today.

It's certainly remarkable and represents a novelty, as you'll see, not quite paradoxical [? now. ?] It only appears so in the light of what I just said. Allow me to go back a little bit to pick up the argument in this fashion. If I were to say, the aether, especially if I spelled it A-E-T-H-E- R-- and I do not mean, of course, the aromatic anaesthetic-- I mean an inevitable something that fills empty space, which is useful for propagating the waves, for example, of light and radio electromagnetic radiation, the classical aether which the physicists of a hundred and some years ago were heavily involved in looking for.

Now, we have that particular aether, a substance whose properties, among other things, included the property of remaining at rest when you move forward, unless you happen to be so lucky to drag some of it with you. That substance has, I think, disappeared from physics. Its disappearance was secured by Albert Einstein and the great changes of the first decade of this century, who showed that, indeed, there was no such rest frame in which light was preferentially propagated, that light was quite happy to go in any old rest frame. And the idea of a stationary substance which propagated uniquely had to be given up.

In fact, if you measure the velocity of light, you need not describe how fast you were moving when you measured it. With respect to anything you might want to point at, it doesn't make any difference, and this has been so well verified in such an intricate network of ways, that very few physicists would be willing to go back on this fundamental proposition. But, of course, substances are very good models for an aether, but the logic is not tight.

It's not required that an aether have all the properties of water or air or steam or anything you might pick up in the shop. That would be nice, but we [INAUDIBLE] can't have those [? properties. ?] [INAUDIBLE] cannot be brought to rest with respect to you, but does that mean that there's no sense at all through which it's possible to see physical properties ascribed to empty space, to what physicists like to call, the vacuum? And I mean the real vacuum, not the vacuum contaminated with what's left over when the pumps have done their best. I mean the real space in between those pieces.

We have known for a very long time now-- since the great days of the early '30s, now more than 50 years, when the quantum field theory got its first realization in [? quantum ?] mechanics-- that there is a sense in which that vacuum is very real, full of properties, but those properties do not include the property of remaining at rest and being like a substance. They are quite different properties, but they still adhere to empty space. More or less as the metaphysical argument, if you need something to propagate, your [INAUDIBLE] would apply, in that sense, I believe the aether has returned.

Physicists are wary about saying that, and they always call it the vacuum. Or maybe the vacuum is [INAUDIBLE]. They never refer to the aether, but that's only because they don't want to raise false notions that [INAUDIBLE]. It is not, but it is repeating itself I would say [INAUDIBLE].

Something [? periodically ?] had this idea back again that's not the same idea. It is [? much less known ?], but we seem to have lots of science for it. I thought we could spend a few minutes discussing that and then show what the latest result is, which I found very striking and good, awesome. What is the [INAUDIBLE] of aether?

Well, we'll take the most familiar one, [INAUDIBLE], because that's the [? field ?] that we understand best, the generalized quantum mechanical extension of the great theory of Maxwell and Lorentz, which, indeed, preserves the exact formulae of Maxwell and Lorentz in their appropriate domain and only deviates from it when quantum effects must be taken into account. So all those things are real. Now, of course, if I have an electric field and a magnetic field, it is [? a vector field. ?] And it could go this way or that way or any old way, and the same is true for either field.

And it is easy for me to imagine the following situation-- a situation of a highly fluctuating field which points in every which way such that the mean value, the average value of the field, is zero. Well, we know that in a vacuum, by definition, there's no electric field. That's why we call it a vacuum, but we still have not answered the fact. Well, it might not be that our measurements, which, after all, always have to average over time and space in some degree, are just getting the mean result, which is zero, even though zero is made by plus and minus and not by zero in some ineffable, platonic way, always being zero.

I'm not sure that's a meaningful statement, but I think the metaphor holds clear. The photons, we know electromagnetic radiation is in photons, sometimes easy, sometimes hard to detect. They, too, must average together. There can't be any photons present, but, indeed, the theory, itself, contains the statement that if you know the number of photons precisely, you cannot then know the exact direction and magnitude of the electromagnetic fields.

Just as you cannot know the position and momentum together in the Schrodinger theory, so in the QED, Quantum Electrodynamics, an extension to that is made of a very similar sort with a very similar mathematical basis. And they worked on it heavily just before the Second World War by Bohr and his group, made fully consistent and given [? richness, ?] [? which is impressive. ?] So everybody now believes that there is a vacuum energy which is taken to be zero. Because its mean value of fields is zero, no photons are present, it's empty.

But that something is going on there seems indicated because when we make calculations according to the best canons of this theory for measurable atomic energy states-- we only can do that in single [INAUDIBLE] atoms, say, hydrogen-- we find that, indeed, [? a turn ?] is always present which corresponds to some effect of this vacuum which is not in the presence of an electric field nor in the presence of a magnetic field. But somehow, we're led into this transient appearance and disappearance of photons and, indeed, of electron and positron charges in the style which many of you can recognize is nicely represented by various complicated Feynman diagrams. All that we can say is that we have reason to believe, good [INAUDIBLE], that there is some meaning to this fluctuating, tantalizing, transient quality of the vacuum which, of course, does not really have any energy, energy that isn't there.

Be real careful about that because, of course, if the field is plus and minus, the square field is not plus and minus. It's always plus, and since the electrostatic energy is the square of the electric field energy, when you calculate the field energy in the vacuum, you do not get zero, as you might like to have. In fact, you're extremely [INAUDIBLE] infinity. But you can whistle and [INAUDIBLE] and say, well, that's obviously wrong, so we'll subtract [INAUDIBLE]. In all situations, practically, you have [? some ?] that are very [? content. ?]

Indeed, an even more striking residue of this idea appears in this way. If you take two conducting plates, very smooth and very cool-- so there's no black-body radiation between them-- and bring them near each other, they attract. And you [? can count those, ?] measure it, [INAUDIBLE]. But be very careful because it doesn't amount to any considerable force except on a micron scale, so it's really quite difficult.

But it has been done, repeatedly, and it gives the right result. And the strange part is, that result can come about from a far-away, somewhat naive, but nevertheless striking calculation. I say, space is full of the vacuum energy, exactly as calculated according to the principles of Maxwell and [INAUDIBLE], but when I put a little pair of plates in there, they truncate the vacuum in between those plates. Short waves, x-rays, et cetera are very happy. But long waves are not so happy because they're cancelled out at the boundary by the two good conducting plates.

Therefore, this space in here, between my hands, which is much magnified, has all the energy states that are high energy, where the troubles are, and so has the space outside. But between the plates, the low-energy part is gone. Therefore, there's a little less fluctuation energy in the vacuum, inside, which is the truncated vacuum, than the vast vacuum outside. And the plates duly come together, and that calculation leads exactly to the observed amount, without any reference, of course, to the nature of electrons or the [INAUDIBLE] or anything of that sort.

The assumption, alone, is enough that they are conducting. They shield the electromagnetic field. Of course, they can't shield the very high energy, so it goes right through them. So you don't expect any troubles [INAUDIBLE] [? cancelling, ?] or it would not play any role. This effect, called the Casimir energy is somewhat puzzling, I think, to anyone who would like to do without it.

I know Professor Feynman spent the last few summers here having conversation often about this topic. He once said to me that he felt that his mission in life was to keep the vacuum clean. But that in four years, [INAUDIBLE]. He still believed the real, proper vacuum was empty and clean, but he'd be darned if he could see how to demonstrate it.

And, in fact, it's always the other way around. The demonstrations [INAUDIBLE]. Well, that's as it may be, but, you see, there's one other element which comes in here, which is related to the famous expression, e equals mc squared. I guess we could say, m equals e over c squared, because since 1915 or so, we've recognized the most important property of energy, perhaps, certainly for an astronomer, is that it has not only the usual properties. But it also has weight.

It has gravitational mass, and this gravitational mass can then be observed gravitationally. There is no longer the argument that the zero point of energy is arbitrary because you can only observe the changes in energy from classical energy [INAUDIBLE]. You can now observe not the energy directly, but its mass, by watching a mass pull your test mass towards it, ever so little. That's what you've got to do.

Nobody can quite do that, but in principle, that should be possible. And so that puts the zero point energy, the energy of the empty vacuum, in a very strange way when you say, it might show up somehow if we can do gravitational experiments. Now, of course, we live in a universe where gravitational experiments are the whole thing. It's only that we, human beings on a tiny scale, cannot manage anything with gravitation.

We can only fight gravity [INAUDIBLE] puny, little things that go 1,000 feet up or airplanes or rockets or whatnot. But gravity, no, no, you don't dispose of planetary gravities and turn them on and off in a laboratory. By their nature, the large-scale universe operates by gravitational forces. I'll have more to say about that next time, but I'll just assert that at the moment. I think you'll probably agree.

And these gravitational forces suggest that if there is a lot of energy lying around in the vacuum, or something like it, you might be able to see it by studying not the laboratory, but the universe. This point was made forcefully and formally, correctly, first only about 10 or 15 years ago by [INAUDIBLE], who pointed out that the term introduced by Einstein for a false reason-- Einstein said he always regretted all his life when he first made the first cosmological theories in 1918. That term, constant, that he introduced then to make the universe static, which he thought was needed, which we know is not the case anymore, we don't need it. Nevertheless, he introduced it.

That term is exactly what you get from the constant tensor put into the vacuum. [INAUDIBLE] [? energy turns into ?] vacuum. [INAUDIBLE] Simply to say, the mathematical formalism of that theory naturally leads to using an energy in the vacuum. It isn't an ordinary kind of energy because it has this fluctuating quality. But it comes out just the same, and it's the same for all observers. It doesn't show any difference whether you move rapidly or slowly through space, so it satisfies the Einstein conditions perfectly.

That was very striking, and everyone felt that that was an interesting idea. By and large, when I talk, of course, [INAUDIBLE] for quite a few years around here, and in the beginning, I always said this was a silly idea. Why invent a whole, new, complicated thing out of a zero which isn't there. We don't see it, and don't worry about it.

And that was the general point of view, and it has come back, indeed, to astonish us. And I think this where the aether has now reentered the world. [INAUDIBLE] I think the next slide might be worthwhile at this point, just to give you the [? field ?] in which all this happens.

I simply show two very handsome galaxies. I want to remind you. We're looking out through our own galaxy at the distant universe, through the [INAUDIBLE] of stars. All of these things here are just stars, moist too faint to see, but perfectly acceptable to the big telescopes and the photographic plates. And here, we see two very well known and nearby galaxies, quite beautiful, which have a lot of history of their own, and I shall take them on next time, in fact. I chose these [? because you're not ?] familiar with them.

[INAUDIBLE] spiral galaxy, well, this is kind of a spiral galaxy [INAUDIBLE]. That's the way it is in astronomy. No physicist will ever take a picture of the most valuable piece of [? laboratory ?] [INAUDIBLE] through a foreground that confuses everybody and against a background that you can't control.

But that's what astronomers do all the time, [? unfortunately, ?] so we might get a nice, clean picture. [? But we can't ?] [? to tell you ?] the truth. So this is the way it looks. Now, the next one, please-- to show you that not everything is what you see in a handsome photograph, I have taken another picture I want to use next time.

Forget that this is a [INAUDIBLE] galaxy, which you haven't seen many like before, but look at the same object that's here and here. You may see the little ring sticking out of the edge, there. Distant galaxy, rather interesting for its funny shape. That's not why we'll discuss it.

I'm using it only to demonstrate that we know only what we can see, or more precisely, what we can demonstrate instrumentally in some way. And here, we see a lot of light around that galaxy. It appears when you do the singular thing of just exposing deeply for a long time, a long-time exposure, and using the right photographic plates. You bring out much more on the right-hand plate than the left-hand plate.

That's just as real as what's inside. I don't say quantitatively how much it is because, of course, it's now all blackened. The brighter parts don't become-- ah, perhaps I should mention that. Remember, in this picture, it's the astronomer's trick. Instead of making the positives [INAUDIBLE], the negatives instead of going through many stages. And the negative is a little easier to understand.

So starlight is black, and black sky is white. Here you see this mess. That's a lot of stars out there that just don't show, and the fact that they hang so closely to this object is they're not part of our galaxy, but part of the object out there. And, of course, many other instruments, radio telescopes and the like, will demonstrate similar lost material, next slide.

Fine, so we see. We have a look around. We find out what's out there, and the most observation does not give you all of the answers. It gives you some answers.

Here is the famous object, classic object. It is called the [INAUDIBLE] Cluster. It's the nearest, large, large, cluster, which [INAUDIBLE] hundreds of galaxies. All these big, spiky things that are not beautifully round are galaxies. The image is so small that not even many full-grown stars show up on it because we've got to the galactic pole, where the star density is not very high in the galaxy.

Fortunately, this cluster was put out there. [? Or put it ?] the other way around. Fortunately, we were made out here, because we're probably falling into that cluster at some rate at the present time. In any case, this is one of the nearest big clusters of galaxies. It has galaxies of all kinds and sorts in it. [INAUDIBLE] It has not only the spiral galaxy, which we showed, which can be flattened edges or really nice spirals. We see funny, spindle-shaped things all over this side [? of them, ?] but it also has objects like this, which is the subject of the story, which is a round object which shows up in the next picture.

So here is the next picture, very beautiful, a great deal to be said about this picture. It's a field as big as our own Milky Way, just in this picture. It's spherical, not flattened at all. It has the benefit of those who can see it well, globular clusters in plenty around it. It's really very, very nice.

So what we can do then, if we're going to ask ourselves what's out there in the universe, we take our pictures with the best exposure we can, and we ask the radio people to do the best they can, and the infrared people, and so on. And we add it all together. So we know how much starlight comes out of a given mass of sun. We know how much light comes from dust, IR, and so on, and we do our best to make a census of this kind, to give a census of the mass in the universe.

Recognize this census surely can err in at least one way. It is not very [INAUDIBLE] at all. So there must be a little more mass, at least in what you see, because by building a better photographic plate or a better cryogenic mousetrap or something, you will see more. And therefore, you know that you're getting less than you can see, but you hope that you've got, you know, the biggest part. Otherwise, why all these PhDs and so on?

But, of course, you can recognize from the irony that that isn't the case at all. What we find is, if we look more carefully, we're seeing pitifully little of the material that must be there, which is demonstrated in this very simple case. It is not a fair case. It is one of the largest galaxies. It is central to the largest cluster in the neighborhood, so I don't claim that it's representative of everything. That isn't my point.

My point is to show how easy it is to convince yourself there is much more present. And [INAUDIBLE] assertion, we find that in many, many cases, not just in this wonderfully-measured example, which is perhaps the best example, next slide, please. You remember that big white spot you just saw was the same as that little black thing that was up in the center of the picture there when I showed the many galaxies in the cluster, and here is the same object, only [INAUDIBLE] through a fancy plate with a thing called a densitometer, a computing light device, which measures how black the plate is and gives you a number for it and then plots that number in the from of a [INAUDIBLE].

When the numbers are high, it makes a white stripe, then when you get low, it doesn't [? do anything to the black. ?] Then it makes a white stripe when they're about half as bright, and so on and so on. And so it converts the plate into a contour map of brightness by machine, and, of course, if the plate has something on it the eye can't catch, like the little margins of the galaxy where there's still light but it's not enough contrast for you to see, this object will display it. And so you see, in fact, around M87, for that's what this thing is, there is this series of lines, contours, showing that there is a skirt or halo of starlight extending [INAUDIBLE].

In fact, this [? circle layer ?] is just the size of the whole thing, which you saw in the previous picture. So low and behold, the thing is now about two or three times bigger in diameter. Now, that's not a great [INAUDIBLE]. Why? It's because of the law of [? uniform. ?]

[INAUDIBLE] [? said, ?] two or three times cubed more volume. That's only 10 or 20 times the volume. That's a big error, but in astronomy, not too bad. Moreover, it's far from uniform. We must admit that the center is very bright, plenty of stars, and the outside is very unbright, not many stars. So probably [INAUDIBLE]

We're picking up. We're getting some of this material in a good census. So the next slide shows a still more modern and wonderful way of making the measurements of mass.

Now, of course, you see that [? I have ?] already done what astronomers love to do today, and that is make art in the form of maps. Don't think this is an angle you could see by looking through any kind of instrument, but it is what an instrument sees, mapped quite beautifully in a certain school of New York style in the following way.

The light [INAUDIBLE] is that same old visible M87, maybe a little bigger in this case than the one you saw before. It's the same old one, but around it, that red stuff, which is in contours again, you see it. But not such fancy contours turning black and white. Now, these contours are all made bright red and a little less bright red and a little less bright red. You can follow it as we go out to the outside of the picture.

Those map the intensity of the light seen on the outside of that galaxy, but it's [? a lot ?] [? more than ?] the light of the eye. It's the light of the x-ray telescope. This was made on the famous Einstein satellite, and it's analysis by [? Gordon Stein ?] and his colleagues at Harvard, very beautiful piece of work.

So you notice, though, that this is not a great, big sphere, and it's all shining x-rays. And, again, something quite remarkable can be said about it. It looks quite uniform. It is really round. It is just about as round and uniform as the object inside. Of course, it's tapering away as you go out. That's fine, but it's radially symmetrical.

So it looks [? as though it's not a violent ?] thing, and this argument's been pursued quite far. It isn't throwing something out or bringing something in. It's matter that has gathered there and is staying there and shining x-rays. That's pretty generally concluded.

If that is true, can we measure what's keeping it there because this gas has a pressure? And that pressure must be opposed by gas on the top of it, holding it in, and that gas on the top of it is held in by nothing but the gravitational force of the whole system pulling it together, exactly as the sun is held together.

So this is kind of an x-ray sun, but on a prodigious scale. This thing that you see is 400,000 light years in radius or more. It's a very large ball, and we can measure at every point the temperature of the gas that makes the x-rays. It fits the argument that it is a vector. In fact, it is pretty similar all the way out.

You could measure the density of the x-ray producing gas from the intensity. That's a direct piece of atomic physics. So we know the density and temperature of the gas at any point. Plus, we know the pressure at any point, thus we know the [INAUDIBLE] pressure. Thus we know how much force is holding the inner layers in, and thus we can calculate how much mass is in the galaxy.

And the mass is pretty impressive. It is more than 100 times, maybe 150 times, the mass which you would assume for it if you just took the starlight that you could see, even extending the starlight with the tricks that we tried. There's a lot of mass out there that we don't know.

This is not the mass of x-ray gas. The mass of that x-ray gas is only a few percent of this total. The x-ray gas is only a decoration, only a marker to show us that there's something there that exerts gravitational force, and we believe it to be-- well, there will be [INAUDIBLE] presently. But it's clearly concentrated toward the center of M87 and goes out to the outside, and this is quite a general feature.

In order to show this a little more generally, let me go ahead [? for a moment. ?] Here is a spiral galaxy, not at all [? distorted in any way. ?] There is the top. There is the [INAUDIBLE]. Here is a spectrum. Notice the jiggle in it. [INAUDIBLE] put into a curve.

What we are doing is we're looking at a galaxy that is edge on. Such a galaxy has to turn like a phonograph record [INAUDIBLE]. And as it turns, this one side is coming towards you, and the other side is going away from you. The astronomer can measure those speeds by the famous Doppler shift, in terms of the speed of light, which is [INAUDIBLE]. This is a slide from [INAUDIBLE], and this is [? what you get ?] there.

Now, once you know the speed of circulation of a planet, you can calculate its distance from the sun in our solar system by what is called Kepler's law. That is a very well known application of gravitation. And if you do this for the galaxy, and you do the same thing, it's not quite so simple. And you'll see why in the next slide.

Here are a few of them. There are 50 more like that, or 30 more. Notice the velocity, which is plotted vertically, against the distance, which is plotted horizontally. It has a lot of wiggles and so on, but it's pretty flat all the way out into the outskirts, which you don't see anything there. Very few stars can be seen in the outskirts, just barely enough to get your spectral lines, and the [? curve's ?] not showing any sign of going down at all.

Therefore, the judgement is extremely easy to make that, again, there's a lot of mass that we don't see, that is not shown in our starlight pictures, [? though ?] it is holding the galaxies in the orbits as directly measured by their speed, and that is quite a remarkable result. Now, so people have added that up rather generously. They can do it not only for individual galaxies, but for clusters of galaxies, for their motions among the clusters, and every effort to measure this mass comes out with the same result.

There is 10 or 20 times as much as we see in starlight. Maybe that's the conclusion, but then there is another argument that makes that conclusion, even, erroneous. So let me proceed to the last of these slides, and then I'll talk about it just a little.

This is a version of the famous red-shift curve, showing in this case standard [? candles, ?] [? being ?] explosive stars, in many galaxies, plotting the brightness [? in some units ?] against-- this is the brightness, and this is the speed of recession. It's called a red-shift curve. These [INAUDIBLE] far right are quite faint. These are [INAUDIBLE]. These are [? close to the ?] [INAUDIBLE], hence rather bright, and the shape and the color is something that can pretty well be calculated.

And the argument that is the most striking argument in the last five years-- I think [INAUDIBLE] headlines, at least-- is the argument that the cosmological [? regularities ?] that we see suggest that we live in a universe which was inflationary. What does that mean? It means simply that the universe's scale in which the universe exists, which was formed very long ago before we were around to observe, is an enormously large scale compared to the one we see, the time scale we measure and the galaxies we see.

These galaxies are older than 3% of the time scale that we know [INAUDIBLE]. That's still a pretty small part of the final curve which we'll someday have. It's only a little, tiny, bit. Therefore, [? it's too straight. ?] But the remarkable conclusion, which has support in [? other places ?] as well, [INAUDIBLE], is the fact that this curve is so nearly straight because, a priori, there is no reason to believe that it should not be strongly curved, either one way or the other way.

And the fact that it is so straight has always been a puzzle. [? We know ?] somehow it was [? made that way, ?] but the new idea of inflation, [? which I'm not ?] going to try to describe in detail, has suggested the reason it's so straight is, in fact, [? because the universe ?] is very much larger than these things. And [INAUDIBLE] observations over a billion light years really don't stress very much the broad sweep of that majestic curve, which someday we might see.

But yet, it did come pretty close to straight, and that's enough to lead to that conclusion. And if that conclusion is right, if this straightness and the remarkable uniformity of the so-called [INAUDIBLE] [? background radiation ?] and a few other points, which I shall simply suppress, are all to be connected-- they're all explained by the same phenomenon-- then that same explanation requires that the mass in the universe be not just the 20 times what we see mass, but again, a number form, let me say, a minimum of 3 to a maximum of 10 or 15 times greater than that.

This mass we just don't know at all. It must be spread on a very large scale because it doesn't appear around these galaxies. It doesn't appear in the clusters. It's spread somewhere, everywhere.

And so, of course, we raise the question, what could that mass possibly be? And not surprisingly, I think we are not prepared to say that this mass which we see is not the mass of space, itself, a very different situation from anything we've seen in the past. The energy in the vacuum, the reason we might say that is that the very source of the inflationary expansion that made the universe come on such a great scale before we arrived-- so what we see are the little pieces of it-- is the use of the energy in the vacuum under the conditions of the strange particles when quarks were not packaged into little groups of nucleons, little groups of three to make nucleons.

In that other matter, the fluctuations in the vacuum were very different since the particles present were very different. And what they made [INAUDIBLE] in their neighborhood was very different, and therefore the vacuum had a lot of mass. And that mass had the curious effect of causing [INAUDIBLE] can't be described physically very well, having the effect of an enormous [? amount of the ?] inflation of the whole universe. Well, if we invoked it once, you can certainly have to worry about perhaps invoking it twice.

And so I think I am prepared to say that we now live in a universe for which we see only a small part, which we know to be stars and gas and dust such as [? existed in ?] [? the galaxy. ?] We know that there's several times, 5 or 10 times as much as that, of some form which we cannot say. It might be more of the same, only too small to see, beyond the contrast [INAUDIBLE], but whatever.

That's [? one contribution. ?] Ordinary matter [? impacts in a ?] strange way, an unusual way. Or it might be extraordinary matter, things that we don't know much about at all that have only been suggested and conjectured in our particle physics laboratories, or it might be the vacuum, itself. All three of these terms would make the same kind of effect, and I, myself, do not see strong arguments for choosing one rather than the other mass.

No particles, no photons, no neutrinos, molecules, axions, whatever [INAUDIBLE] you may imagine, none of those, all flat zero on the average, but the transientness nevertheless could give rise to an energy [? conflict. ?] Of course, it raises the other question. Is my energy rule going to work forever? Namely, if I could change this vacuum to another vacuum, [INAUDIBLE] might [INAUDIBLE] release that energy?

That [INAUDIBLE] would happen when the matter changed from the old, prenuclear matter to the new, present nucleon matter [INAUDIBLE], and for all we know, that might conceivably, though we don't think so, be possible again. In any case, it is better to say that the story of energy and its measurement by using gravitational forces to measure it is a whole startlingly new story which I think has rehabilitated the notion of the aether in another form. Now, I want to come to my third item, just quickly.

If this is the history of a single concept in science, albeit a very important, major one, how are we going to manage to prepare those people who have to make the world run, who are not the scientists and engineers of the day, to deal with this sense of change and sense of argument all of the matters have been trying to exemplify in this [INAUDIBLE] [? system? ?] I think we have an enormous responsibility to try to do that. I don't think it will be easy, nor do I believe that it will succeed in the sense that there will never be famous paradoxes that cause stock prices to go up or learned nonsense in the pages of the *New York Times* in the same connection or even enthusiastic [INAUDIBLE] that have been beaten back for six years still say they are working on a car that's going to work next year, 8 to 10 miles to the gallon of water. [INAUDIBLE] that's something else that's not involved in the rational domain.

But here in the rational domain, given the domain of experience, I think they have the grave, heavy responsibility to try to translate to mostly the kind of thing that one can say here. And I, myself, believe it cannot be done by teaching, however carefully, the conceptual structures, the analysis, and the received doctrines, however compact and helpful they are. They are helpful. They can be taught. There's no question about it.

They do get along in some degree, but I think that what must be [? dropped in ?] instead is the sense that arguments are finite, that details have to be examined, that reconsideration of the same structure might lead to a different thing, that you have severe, logical demands that you can try to change something, all of these points, which don't come out, I fear, of the usual structures that we try to impose when we try to give the results of science to students. I think the only place this can be done extensively in our present institutions is, of course, widely and formally on television and Disney and everywhere else. But above all, it must be in schools, somehow, because that's where the children are, by law and reality, unless we wish to develop a society, which we are in some danger of developing, in which a fundamental, intellectual, conceptual vision crosses it like a great chasm.

[INAUDIBLE] I think that is important. We have to do our best to make this work in the [INAUDIBLE] school [? book. ?] I learned this theory very strongly under [? Gerald ?] [? Zacharius. ?] That would be 20 years ago, and I still believe it intensely.

We live in a world of simple rich, the simplest pour out of the television screen, at two megabits per second. We live in a world that [? is experience ?] [? low. ?] The school kids do not see the moon or the stars or milk the cows or even handle the gardening rake, not much, maybe in summers, but not [? ground. ?] And this is a different time. We do not live in the time of Jeffersonian [INAUDIBLE] [? holders. ?]

We are in a time of crowded cities and easy, symbolic access to pictures and results and structures from all over the world, brilliantly and markedly portrayed. I don't deny that. [INAUDIBLE] but it's not the same thing as some experience with this stuff, itself.

And so I'd like to show a few slides which celebrate that point of view and try to say-- well, I think they say to me, [INAUDIBLE]. These are some old slides and some new ones. This is a new one, lent to be by [? Larry Zobrasky ?] of the Children's Museum. They're [? looking at ?] a scaling problem. This is a bubble.

Perhaps many of you have not seen such a large bubble. The limitation on bubble size is not easy [? to find, ?] and if you [? find one, ?] [INAUDIBLE]. It is my opinion that common sense, which we all have in some degree, that common sense says the glass is empty when it's on the shelf, whereas, of course, it's filled with air. But it's common sensical to say it's empty because when we fill it with water, absent any lid, it's fine.

And we can't drink anything from it when it's just air. And only if you are a submarine sailor or a welder or a gas physiologist or an aquarium keeper or something like that, you begin to understand that air is just as important and just as interesting as stuff in glasses as water. And, therefore, common sense is not different in nature, in my view, from science. It's rather less tested, but the reason it works is you are given the glass and the [? workout. ?]

It's all [INAUDIBLE]. Light doesn't travel anywhere. Light is there. All of these simple things, animals grow. They're just there. They're on the television screen. They are [? beautifully growing ?] on [INAUDIBLE], but the task of animal husbandry, of raising a real, live animal from start to [INAUDIBLE], these are not available.

And what is substituted instead is a rich and powerful and valuable symbolic overlay, but I feel we are in grave danger, if that continues to grow so cheap and so accessible as it has grown, of losing the substance behind the shadow. So I feel the common sense of these bubbles will never be forgotten by those kids. I'm not saying it's important to know if bubbles can be large. It isn't, but there is something about that phenomenal extension which I believe will make an important difference to some of the people who work in this context, of course, not for a single thing.

It's only one example I chose at random, but imagine a hundred things like that-- next slide. Here, to help review what I'm talking about, is a [INAUDIBLE]. That's not true. I could [INAUDIBLE] great deal of affect, [? but affect with ?] ontological structure as well. These are real worksheets of real kids, presented with real [INAUDIBLE] with their real, rather difficult names, like Feldspar and so on, and the categories are not just the categories that they learned in [INAUDIBLE] books.

[? They are the ?] categories that they have worked out, and they've put samples, like [? weight ?] and shape and length and width and so on, the shininess and a few others. Now, after class discussion [? of the worksheet ?], it'll turn [? out that we didn't ?] understand that the size of a sample doesn't mean [INAUDIBLE] because of the nature of the person who [? printed ?] the book. And that's a [INAUDIBLE].

But we've got to do that. If we just say we're going to measure the-- [? what do you call, ?] the streak, all of those things you've learned in your algebra. That's very good for the expert who's done all these things. Nearly every meteorologist [INAUDIBLE] has played around a great deal before he becomes one of those experts, but that's the thing we owe to everyone-- the right to play in an environment that is not the common-sense environment where everything has a purpose and has been developed wonderfully to suit that particular purpose unconsciously over generations or by clever inventors, much cleverer than we are, so we can [INAUDIBLE] on the television screen, and the next slide.

These are kids looking at the roots. Yeah, plants have roots, but you never see them, next. Here is graphing [INAUDIBLE]. How were these graphs made? Well, not very much-- you can see this one is not quite the same as the [? others. ?]

[INAUDIBLE] graphical representation [? developed into ?] [? this programming, ?] but how were these graphs made? These are real graphs. These are not mapped by proportionality on anything. They are [? mapped ?] like [INAUDIBLE]. A plant is growing. The child has a plant assigned to him or her.

The child takes a tape of paper. Of course, that's being discussed and worked out. A little tape is then [INAUDIBLE] the plant. That's day one, and so you put that in your report. And then comes the next day two. You put that in the report. And then, next, day three, [? and after, ?] if you were very good, you'd write the day on it.

After a while, you start [? bringing more, ?] and by gosh, you do see some in the next slide [INAUDIBLE]. These are very nice growth curves. And I have even seen a wonderful one, though I couldn't find it, where the weekend intervened. [INAUDIBLE] Now, [INAUDIBLE] old time's sake, but that's exactly what [INAUDIBLE].

It's not really very much, but it's the kind of problem you get into. The systems, if you are involved in a classroom, even for small children, are often very complex systems. [INAUDIBLE] or engineers or architects. Sometimes, it's [? not silly, ?] but sometimes, yes.

And this is the case of an experiment we tried a long time ago which became world notorious. We received scores, maybe 100 letters, especially from the British Commonwealth, full of wonderful stamps. [INAUDIBLE] And they complained we must be telling an untruth from this picture because [INAUDIBLE] for 50 years. It could not be false because that's what you've been telling your kids all this time. But it was false because it wasn't an experiment.

It was a word mapping. They knew what the result should be. It was easy to say in a sentence. They did an experiment that vaguely resembled those words, and they felt without controls, without tests, without analysis, without repetitions, you know, the varying conditions, that they were right. And they were not right, and this was [? a clincher. ?]

The experiment is this. You have a burning candle, [INAUDIBLE]. You see it from the picture. You put a jar over it. The candle duly goes out in a short time. Now, if you do this in a trough over water, you will find, not much to your surprise, [INAUDIBLE]. And the water rises in the container.

And you look at it and squint a bit and say, what do you see? The candle has gone out, and there's no oxygen. It's burnt out 20% of the air. That's what's the oxygen. You see this in the demonstration.

Of course, it has nothing whatever to do with it, and the demonstration that we [INAUDIBLE] was if you put a mouse in there-- that is not a sick mouse. That is a mouse trying to eat a candy bar. The editor of science, a very nice man who published this paper [INAUDIBLE] 20 years ago, he was so worried about the contention that arose that he actually-- I know the man he probably went to.

He went to a very distinguished gas physiologist in New York who had wonderful analytic means for measuring gases. He would trust [INAUDIBLE] experiments. He had to go out and take [INAUDIBLE] samples of all of these gases and analyze them [INAUDIBLE] to 1% of [INAUDIBLE]. [? He showed it. ?] He was right.

Of course, what happens is the gas in the air is heated. The [INAUDIBLE] prevention stops. The air goes out [? because it had higher pressure before ?] [INAUDIBLE]. And very little of the [INAUDIBLE] oxygen is burnt out. 2% is a good number, and the mouse is still quite content.

So that's the story, and I think I have a final one which is more engineering in nature. A beautiful [INAUDIBLE], what was that again? [INAUDIBLE] Ah, well, maybe you can see. These are polystyrene cups. This is the famous chain of cups pump.

You can see prototypes of it in the Children's Museum, and it's quite nicely [INAUDIBLE]. And notice [? the volume of the space ?] [INAUDIBLE] by building it out of simple materials. This is [INAUDIBLE].

Now, finally, I wanted to not talk so much about [INAUDIBLE] [? and then do ?] everything symbolic, so I was lucky enough to encounter a friend and colleague from Harvard. [INAUDIBLE] graduate-school education [INAUDIBLE], but I'm working on a little system, which this is this system. I won't try to tell you [INAUDIBLE]. [? It's a very nice ?] system [INAUDIBLE]. It floats quite beautifully [INAUDIBLE].

But as you'll see, it has Aristotelian [? information ?] [INAUDIBLE]. It always wants to float at a certain height. That system is worth investigating if you've never done it. It's, of course, just a floating balloon with a string tied to it, weighting it down, but it's not going to hang on the bottom. It's not going to rise any farther. It just likes it the way it is there.

But I use that as evidence for Aristotelians, and I am in this first talk a little late, I'm sorry to say. [INAUDIBLE], and I hope I have inspired a few, encouraged a few students and faculty. Look into the question of taking some of your effort and some of your time to study the fascinating systems that exist at a level of simplicity in the context of your public schools. Thank you.

[APPLAUSE]