PROFESSOR: OK. Welcome back, everyone, and me too. I just came back from Boulder where I gave eight talks. I was on seven panels and gave one separate talk, most on education.

And one of the talks was on teaching how to think or what to think. So there were three panelists, one professor from Berkeley in the astronomy department, who is also a renowned teacher, and then an investigative journalist, and then I spoke. And we all said something for about 10 minutes. I talked about the history of education and why it's difficult to change educational institutions and educational practices and what the original purposes of the schools were, so some of this material that I'll talk about in the second to last lecture on political barriers to educational change.

And I then also, before this whole session, I described to the reporter for the *Daily Camera*, which is the paper in Boulder, a bit about what I was going to say. And I talked about some of the material I've told you already about multiplication table. So if you remember, the multiplication table, when people get brain damage in the arithmetic area, they can't do addition anymore, but they can still do the multiplication table. And when people get brain damage in the language area, they can still do addition, but they can't do multiplication anymore. And that's because multiplication, generally, is learned as--

So when you see it, you think of symbols and math, but actually the way most people learn it is 6 times 9 is 54. Then you have to memorize yet another fact. 9 times 6 is 54. Oh. And then you have to learn yet a new fact, that these two facts are related, when, actually, if you understood the meaning, there would be just one fact.

So now you have to memorize all these linguistic sentences. And no surprise, when you get damage in the linguistic area, that kind of multiplication table goes away. So I said to the reporter, yeah, what we really need to do is teach multiplication and math in a whole different way.

So the reporter, she understood everything and said, oh, that's really interesting. I'm actually studying education myself, and I have children. And I'll try to apply that with my children and in the teaching that I do. I said, oh, great.

So then, I gave my talk, and then the moderator asked everybody, well, does anyone on the panel want to say anything to anybody else? And so Alex Filippenko from Berkeley, he stood up and he said, well, I agreed with everything that Sanjoy said, except he was quoted in the paper this morning as saying we shouldn't teach the multiplication table. So that whole discussion, which seemed to be completely understood, just got condensed into one sentence.

So now I didn't actually have to say very much in response, because the second panelist, as I mentioned, was an investigative journalist. And what she was talking about is how you have to be very skeptical of what's in the media. So all I had to do was look at her for a bit, and then everybody started laughing because the point was clear. But then I explained to everybody else what I'd explain to the reporter.

That's by way of saying that education is a complicated subject, but the audience understands a lot more than the media does, which is one of the barriers to political change is that there's people who understand lots of individual points, but how do you assemble it into a coherent plan for change? Well, you need forums for discussion. And if the reports in the media are, oh, don't teach the multiplication table, or do teach it but do it with lots of drill, well, it's hard to get in a discussion of, well, actually you'd like to teach it in a different way, where instead of memorizing this you say, well, 6 times 9 is like 6 times 10, which is 60, minus 6, which is 54. So there's no space for putting things like that into public discussion. And one of the purposes of classes like this is to do that.

OK. Today, we're going to talk about lecture planning and performing. What we've done so far is the flow of the ideas in this class has gone as follows. So this is a logical flow. We did it slightly out of order, because it's the preparation flow, slightly different than the logical flow.

You work out your course goals, or even your curriculum goals. And then you decide, how are you going to tell whether you've reached those goals? Let me just write the goal a little clearer. And with problems, tests, that's the way you operationalize your goals. And then given that you have those kind of problems, well, now you have a pretty concrete idea of what it is you're trying for, because you have concrete examples of it. Well, lectures, recitations, so I'll put et cetera here. What do you do with your contact time?

This is the overall structure. This is at the level where it makes concrete sense. And this is, what do you do when the rubber hits the road, what do you do in lecture?

Last time, what we did is we talked about interactive teaching. And there was, basically, several time scales over which you can make the class interactive. The longest time scale was the wood blocked example, and I'll answer a question about that in just a moment.

So now, continuing the theme of where the rubber hits the road, today-- Now that you have some techniques, how do you assemble it into a lecture? And I use both words advisedly and deliberately.

So plan, it's essential to plan. And performance is essential. People forget that. They forget that lecturing and teaching is a public act, and when they forget that, the lectures are flat.

We're going to talk about the techniques for doing that, starting with the Walter Lewin lecture that you watched for today. Because he actually has many, many examples, I think mostly good, of performance, and some that I think he could improve on. And we'll discuss that and work out and induce general principles that you can use.

OK. Those are the questions from last time. There was a slight review of interactive teaching as well and things like this. Now the question is, what do you do in lecture? How do you plan, and how do you perform? And a good way to start discussing that was actually to look at a master of the art and see what they do.

Now no master is perfect. But I think Walter Lewin did so many things well it's really worth understanding what he did and looking at it. So what did you notice from your homework problem? Basically, what did you notice that he did? And I have a bunch of things as well.

And we'll just write them down. Because what we'll do, as before-- we've done this several times now-- by looking at examples, we can induce general principles. Actually, I'll leave this here, and I'll erase these guys.

While I'm erasing, just pull out your homework and the things you've noted down. And actually, take a minute and check in with your neighbor and see if your lists overlap. And sort of vet your lists with each other. And if you didn't think about anything that could be improved, see if you can remember anything that you would have done differently.

So let's share all the points. So I can see that you've come up with a lot of examples, and I actually had a bunch too, because it's such a rich lecture. So let's see what things that were done and what was either that you would keep or you would change. And I'll put them in one or the other side, according to how you categorize them. Any one example? Yeah, Wendy.

AUDIENCE: He awards students when something might not be intuitive for them or something. So when he was doing analysis of error under the square root, and he was saying, OK, this might not be something you would know right now. I might not hold you responsible, but it's interesting [INAUDIBLE].

PROFESSOR: OK. So he tell students, look, this is harder or not intuitive. He gives them a gauge and tells them, look, you're don't have to worry about it before he says something. He gives the difficulty of something. OK. Why is that helpful? What does that do for students? Yeah.

AUDIENCE: It sort of removes the tension of thinking, oh, man, I don't know this while they're trying to pay attention to the other [INAUDIBLE].

PROFESSOR: Right. Right. So it differentiates the lecture. So I'll put in other color the reasons. Yeah, so it gives some kind of differentiation to the lecture. It gives a structure to it. It gives you a way of evaluating so you know what are you supposed to be doing here and trying to learn from it. You don't all of a sudden trigger your reflex fear. So it minimizes fear.

And it gives a clear expectation. So in the particular lecture, he didn't say anything was you absolutely have to know this. So there wasn't a flip example. But if it had been a flip example, it would have the same benefit.

If he said, oh, this is really fundamental. You really, really, really, really need to know this, well, that also punctuate the lecture. So it minimize fear and sets expectations.

To expand on this point, which is really fundamental, think about the difference between the way a novice perceives something and the way an expert perceives something. If you want to know how a novice perceives something, try to remember from the days when you were not a chess Grandmaster. That shouldn't be too hard for most of us, certainly not hard for me.

You look at a chessboard, all the moves look kind of similar. Oh, I could move that pawn. You think about that for a bit. You analyze some moves.

He takes, I take, he takes, I take. Hmm, OK, let me think about-- I could move the rook. I could castle. He takes, I take, or I'll move the bishop. And you sort of say, OK, I'll move the bishop. That's how the novice or medium chess player thinks, speaking from personal experience.

The way the master or the Grandmaster looks at the chessboard, the chessboard has meaning. All the different pieces of it are kind of talking to each other. Hmm, that pawn structures is really full of holes. You really want to do something about that. So the undifferentiated mass of pieces that the notice sees is completely different from what the expert sees, which is why the expert can remember the chessboard and the novice can't.

I noticed this exact same thing happened in my freshman year. I learned to play bridge I'd never played bridge before, and all my friends, who I don't know if they did me a favor or not, taught me to play bridge so I could play bridge with them.

When I first was playing with them, at the end of the hand, everyone does the post mortem. You have four people, you play all the tricks, and everyone talks about what happened and it didn't happen. And they would say, Oh, yeah, why didn't you play the queen then?

I was like queen of what? What queen? Did I have a queen? I didn't even remember the cards I had. I didn't even remember how many cards I had of each thing.

I just sort of remembered the last card, maybe. Or more like, oh, phew, the hand's over. OK. I can't make anymore mistakes.

That's how I would see it compared to how they would see it. And I was like, how could they ever even remember who had the queen of what? And by the end of, I don't know, six months, I would say, uh, why didn't you play the five then?

Because all of a sudden, now I was doing exactly the same thing. The hands had meaning. The cards had meaning.

So by doing this, by giving clues to the difficulty or ease of things, you're actually giving meaning. You're transferring some of that knowledge that you have as the expert to the student, who otherwise wouldn't know.

There was another example of that in the lecture where he said, this is the most important equation in all of physics. He wrote that, and he boxed it, and he said, that's probably the most important equation in all of physics. So again, he's giving something that the expert knows. Because the expert knows, oh, yeah, when you see this, you're home free, and you know you can model so many physical systems with this. Let's tell the students how important it is so they have some way of thinking about it.

OK So that's really fundamental. Others? Other points? Yes.

AUDIENCE: He uses big ideas and terms for them, like uncertainty and restoring [INAUDIBLE].

PROFESSOR: OK. So he uses clear terms for big ideas, and he uses the same term each time. He's careful to do that, so you don't wonder why it changed. How does that help students, to give things names and repeatable names? Yeah.

AUDIENCE: Gives them fewer facts to [INAUDIBLE].

PROFESSOR: Yeah. It gives a structure to everything. It's gone now. But it gives a structure, repeatable abstractions that you can reuse over and over again. Structures.

In fact, it's another example of this. It structures the knowledge. So it's structured in his mind. He's the expert. He has a really good, sound flexible structure. And part of the job of really good teaching is to help the students build that structure. Yes.

AUDIENCE: When he's characterizing visions, he really emphasizes building intuition for why the vision is the way it is and why it's [INAUDIBLE].

PROFESSOR: OK. So he emphasizes the why of the equation. So why is it plausible that it, for example, has-- Can you give an example of that?

AUDIENCE: He talked a bit about why [INAUDIBLE].

PROFESSOR: OK. Yeah. There was an example where the frequency was derived, so emphasizes the physical meaning and interpretations also. And interpretation. So the example he gave, which I think is a good one, is in a pendulum, why is the period independent of the mass? For a pendulum--

OK. And the argument for that was, oh, well, if you double the mass, you double the force, but you double the mass, so you haven't changed the acceleration. So everything stays the same. And he contrasted that. He didn't just do this one. He contrasted that with what happens in a spring.

OK. So how does this help the students? What's the benefit?

AUDIENCE: I think it helps them because it makes them feel like they could potentially derive it themselves and then afterwards check their answer.

PROFESSOR: OK. Right. He's modeling, actually, what you would do. You, yourself, as a physicist, and hopefully as a student, you want to be able to check your answer by making sense of it. It promotes sense-making is a shorthand for it. Let me just push the other board up.

AUDIENCE: Well, and it's also [INAUDIBLE].

PROFESSOR: Oh, sorry.

AUDIENCE: --which is probably the most difficult thing to teach. I thought that was the best part of the lecture. One thing is to give a list of facts so you learn and then you can use.

PROFESSOR: Right.

AUDIENCE: That seems to be the closest to teaching how to think, which is the most difficult thing you can ever teach.

PROFESSOR: OK. It teaches how to think, because it's a transferable skill. You may never have to analyze a pendulum again as a student outside of the class. But whatever formula you get, you can use that same method to say, does the formula make sense? So that's teaching a way of thinking. It's a transferable skill. Yeah, Adrian.

AUDIENCE: He's very, very explicit about his notation.

PROFESSOR: OK. Explicit about notation. Can you give an example?

AUDIENCE: Well, even when [INAUDIBLE] method of a string, he says, this is the method of a string. And he'll label an equation with the whole, writes it out. In [INAUDIBLE] terms.

PROFESSOR: Right. He'll write everything out. So he's very explicit about notation. How does that help the students? What does that do for them? Yes.

AUDIENCE: It makes it clearer and it makes mistakes hard to make.

PROFESSOR: Right. It makes it hard to make mistakes. Again, so this is hard to make mistakes. Harder-- OK. And what makes it harder, and why is this so important? Because, as Adrian said, yeah, it may be intuitively obvious to the expert physicist that, of course, L is the length. That's why you chose L, because length begins with L. But for the student, everything is new.

The chess example, the knocking down the chessboard problem and seeing how well you can reconstruct it, explains so much. The novice, they can't reconstruct the chessboard. That's because each piece on the chessboard is not intuitively obvious.

Whereas, for the chess master, it's so easy to reconstruct the board, because, to them, it is intuitively obvious that, of course, you have three pawns in front of your king. Unless you have some really crazy opening, of course you've castled your kind and you have three pawns sitting in front of it protecting it.

And it's just obvious from the configuration of the pawns that, of course, with that pawn configuration you did this opening. And of course, the king is defended in this way. So what's obvious to the expert is completely obscure to the non-expert. You want them to not have to worry and fill up their short-term memory slots with things that really are obvious, so you put that right on the diagram.

He wrote M, I think, and then there was an L there. So right away, you just look at the diagram. You know what L is.

OK. Other things that were done? There are so many.

AUDIENCE: He asked the students to help [INAUDIBLE] passively but actively.

PROFESSOR: OK. He asked for help. That increased participation. How did he ask for help? What were some examples of that?

AUDIENCE: [INAUDIBLE] the gun spray toward the [INAUDIBLE] of the harmonic motion, he asked a student for help holding the end of the paper.

PROFESSOR: Right.

AUDIENCE: And then, when he drew the big pendulum where he--

PROFESSOR: Oh, the final pendulum. Right. Several times, actually-- let's see. I think I have it here-- Lewin says, I want to hear you loud, because he didn't hear them. He wanted people to really participate, and then they really started counting. So they were really involved in what's going to happen by the end of 10 swings. It involved them, so it's a form of interactive teaching. He's getting people more involved. Yes, Adrian.

AUDIENCE: On the other hand, I thought he pretty much never asked questions.

PROFESSOR: OK. He didn't ask them questions. Right. Yeah, it's good that he asked for help, and that is one way of involving them. So it made them interested, but it didn't necessarily-- It increased their motivation to learn about the subject, but it didn't necessarily actually help them learn right then about something. So he would change.

OK. Can anyone else think the spots where he could have asked questions? Yeah.

AUDIENCE: I think there were natural pauses, natural breaks [INAUDIBLE]. For instance, when the air tracks through the pendulum, he didn't stop there. He never stopped to let students think about what they [INAUDIBLE].

PROFESSOR: OK. He didn't pause at the natural break points.

AUDIENCE: He didn't pause at the natural--

PROFESSOR: Yeah.

AUDIENCE: [INAUDIBLE].

PROFESSOR: Right. One example that I remember of that, because I was also watching for that, was he wanted to show Hooke's law and he plotted out-- I'll draw an example here.

He plotted force verses extension for a bunch of extensions. And forces was the weight of those springs. And he got a bunch of points here, and he drew this.

Then he pulled one of the springs, and he stretched the hell out of it. And then he let go of it, and it came back much longer than it started. And then he drew what happened on the graph.

So one thing he could have done, rather than drawing it straight, is the following. You say, OK, how do we describe what happened to that spring as I stretched it? Was it this curve, that curve, or that curve? A, B, C. You don't have to spend long on it, just 10 seconds, or even 30 seconds.

But instead, he just told them which it was. So actually, which was it, A, B, or C.

AUDIENCE: C.

PROFESSOR: C. Right. It was C. And just the act of thinking about that forces you to connect the physics and the mathematics once again, even this small amount. Yes, Lat.

AUDIENCE: Wouldn't the same apply to you? I've never thought about asking a question. Maybe you answered it immediately. [INAUDIBLE].

PROFESSOR: Right. OK. He didn't pause at natural break points, and he didn't pause at--

AUDIENCE: [INAUDIBLE] smaller time scale?

PROFESSOR: Yes. Not the smaller time scale. Right. No five-second pause. So the questions are almost rhetorical. I would say it's one of the dangers of being such a good performer, which he is. He's fantastic, I think. And one of the things he does so well in his performance is connecting-- which you mentioned over here-- the physics and the mathematics, explaining the physical meaning and interpretation, that top item.

He does that so well. But one of the dangers of being such a good performer is that you just steamroller over the students, and you become, in some ways, more important than the students. Yeah. You'd be able to do less in lecture, but the five-second pause is really important to have everyone tracking and following with you.

Other items? Let's see. Someone I haven't-- Yeah, Tsu.

AUDIENCE: Sometimes, when he says, this is totally non-intuitive, he kind of just accepted that. And I think it would have been nice if he had given a reason for why this had to be, instead of just saying--

PROFESSOR: Yeah. OK. When he said things were non-intuitive, he sometimes didn't explain why it was non-intuitive. So the one I'm thinking of is he said, no matter what the amplitude is, the period is the same. And he said it isn't intuitive.

So that was good, in that he did tell people-- Where was that? Yeah, it's here. He gives a difficulty. He says, for example, this isn't intuitive. You should be surprised that the period is independent of the amplitude.

But he doesn't give them another way of seeing why it should be. They do the derivation, and you find that it is independent of the amplitude. But why?

And you can explain that sort of intuitively just by saying-- I'll give you a quick explanation of that. So it is, actually, an amazing fact. I'll give you a quick explanation of the unintuitive fact that the period is independent of the amplitude. OK?

This is a scaling argument. E, G. OK. Let's estimate how long it takes a mass to move a distance, A. Well, it has some acceleration, a, small a. This is the amplitude, and that's the period. So the mass has some acceleration, little a.

And in some time, t, the period, or some fraction of the period, let's say a quarter of the period, it goes this distance, give or take factors of 2 and whatnot. So this is roughly the amplitude.

Now we want to figure out, what is this A here? Well, A is the force over the mass. And the typical force, that's coming from the spring. So it's a spring constant times the extension. The typical extension is the amplitude. OK?

k times A is your force, divided by m, so we'll put that in there. OK. Oh, look at that.

Hmm. And in fact, there you have t is proportional to square root of m/k. So you've got not only that it's independent of the amplitude, but you've got the whole story, except for the 2 pi.

So intuitively, what it's saying is that, yeah, if you move yourself farther out, you have father to go. But you're pulled harder by just enough to make the time the same. And so not only is it an intuitive argument, it's very plausible. And Galileo extended it to the pendulum, and he thought he found a proof to show that the pendulum actually has a period independent of amplitude.

In the pendulum, the amplitude is related to the restoring force, so he thought the period of the pendulum was independent of amplitude, not just for a regular spring. And that proof turned out to have a slight error in it. But as Walter Lewin pointed out, that's only true at large angles, and at small angles, you can't tell the difference.

So you can actually explain these non-intuitive pieces in short ways that don't require doing a full calculation. And that is important to do, I think. OK. So why don't we take a 10-minute break, and then we'll-- Oh, do you have a quick comment? Go ahead.

AUDIENCE: One other thing that I thought he should have done.

PROFESSOR: Yeah?

AUDIENCE: Which is actually motivate why this is so important. He mentioned [INAUDIBLE], as you said, that it's the most important thing in physics. But actually, I thought it would have been nice to give some real examples of how [INAUDIBLE].

PROFESSOR: OK. Yeah. Answer the "Who cares?" question. Right. And that's a good point. I teach physics myself, so actually that one slipped me. Because this is, again, the expert blind spot.

So he put that equation there, and I was so glad he said, most important equation in physics. And to myself, I thought, yeah, right on. You use it in electromagnetism. The whole theory of quantum electrodynamics depends on it. You use it in modeling materials. It's everywhere.

So all those thoughts went through my mind right away. And I thought, wow, that's equivalent to him saying it. But actually, it's not, because the students, of course, have none of those thoughts. And you really do need to say all that. Why?

OK. We'll continue after our 10-minute break. And then we'll induce our lessons for lecture planning and performance, and I'll give you a structure that you can use when you plan and perform your own lectures. OK? There's several more points to come out.

So we'll take some more points about Lewin's lecture at-- It's 10:05 by that clock. -- 10:15 by that clock. And if you didn't get a comment sheet, just grab one on your way in or on your way out. And I'll be here if people have any questions during the break.

So a few other points. Let me give you one point from Lewin that I noticed and take some more points from you too. One I thought was very interesting, and which is not normally done in most physics lectures on springs. The way it's normally done in the physics class, you would do simple harmonic motion, you'd study a whole bunch about the spring, and then maybe a few lectures later, you might get to the pendulum. But Lewin actually did both in the same lecture, which I thought was very interesting and a really excellent choice.

It had some negative effects, which is that there's less time to talk about things like this. And maybe it feels like there's more pressure to not wait five seconds. So it has maybe subtle pressures in the wrong direction, which maybe could be mitigated by planning. But it had a really great advantage, which is that it's this figure.

So if there's some idea you want to teach, and the idea you wanted to teach is simple harmonic motion. He called it Simple Harmonic Oscillation, SHM is the standard jargon in most of the physics books. If you want to teach that idea, just showing it in one example is not good enough for the students, because they can't separate the example from the idea. It's just one big morass, and they can't draw this dividing line.

So you have to give them another example. But if you give them a second spring example, then it's still too hard. Suppose you do this and yet another spring example.

Well, the problem is it still the overlap here is too big. So you need an example that illustrates the core idea but is quite different. And the pendulum falls into that pretty well.

It's different, in that-- and the order was correct too-- he first did the spring, because the spring really is pure simple harmonic motion. The pendulum isn't, but you have to approximate to get it there. So it shows how you get to simple harmonic motion, because you've seen it now. And so the piece you're getting to is the common thing between the two examples.

And furthermore, it's different enough that you can see what's common and what's not. What's common is the structure of the equation. The structure of the equation is-- So that's common.

And so you have a really particular example here of inducing the core idea, which is if you just did simple harmonic motion with the example of a spring, students may think simple harmonic motion is this. They think whenever you have k/m you have simple harmonic motion. Whenever you don't have k/m, you don't have simple harmonic motion. They may think that actually it depends on exactly what's here.

But because the second example has something completely different-- The second example, the pendulum had g/l after approximating it. You get the same structure of the equation, but a new physical phenomena. And it shares the common feature of simple harmonic motion. So it's a really excellent way of bringing out this idea and borrowing most of the derivation that he did before.

For example, he didn't have to do resolve this equation with these new parameters. Once he'd solved this equation, all he had to do is substitute this into the solution and get the new solution instantly. OK? Yes.

AUDIENCE: He created emphasis by using both gestures and also modulating his pace and pitch.

PROFESSOR: OK. I'll try to squeeze it in here. So he modulated his pace and pitch, and his gestures were very bold.

He talked about the spring. He stretched the spring. He actually almost broke the spring. Whenever he was describing something, you could feel him feeling it in his own body.

His gestures were bold, and his pace was varied. OK. How does that help? Yeah.

AUDIENCE: Conveys enthusiasm.

PROFESSOR: Yeah. It's exciting. It conveys enthusiasm. It punctuates.

There are several languages, I think, which have no vowels and-- Not no spaces. Well, German approximately has no spaces. That's not quite true. But that don't have vowels or punctuation. In the old days, for example, there was no punctuation. People just ran all the words one after another. You didn't put a period at the end of sentences.

Without punctuation, you have to work really hard to figure out what are the units of thought. So by varying your pace and pitch, you convey enthusiasm. You convey enthusiasm and structure. So the pieces that are more important get more importance, because they're emphasized accordingly.

That's actually fundamentally important in writing. I don't know if you know the following recipe, but this is the first-order term in good clear writing. Let's call it not fiction writing but expository writing is the right word.

The first-order term in punctuating writing and giving structured to your writing is this. A sentence starts with old information that links to something before. It continues to--

This is how the sentence ends. Whatever you put at the end of the sentence, readers expect that to be the thing that you want to emphasize. That's the new information. There's maybe a fair amount of new information in the sentence, but this is the new interesting information.

This is what readers assume has emphasis. And in the beginning of a sentence, they look for things that connect to what has already happened. It could connect to the last emphasized thing in the last sentence, the subject of the last sentence, the thing that was the topic, or the topic of the paragraph. It somehow links to stuff before, and then you're going to say something new about it.

So if you don't use that order, it gets very confusing for readers, because they expect this to be emphasized, but you're mentally emphasizing something else, and then they have to redo their expectations each time. So punctuation, the period actually is a way of saying, here came the most important information. And if you follow that structure, you'll tap into much better how your readers understand.

If you want to know more about that, I'll put some references on the website. This was partly developed by Joseph Williams, a linguistic at the University of Chicago and George Gopen, who's an English professor and law professor at Duke. And he's written a really interesting article called, him and Judith Swan-- it's called "The Science of Science Writing"-- where he gives a whole bunch of examples of restructuring prose along these lines and how much clearer it becomes.

And he's written two books, actually, one on teaching this approach to writing and one on doing it yourself. It's a textbook for such a class. One's called *The Sense of Structure*. I forget whether that's the teaching book or the textbook. But I'll put both titles on the website So I highly recommend that. And what you'll see from this is the huge importance of punctuation.

And here, it's the same thing. By varying the pitch, by giving periods, semicolons, and commas in the lecture, even though you can't say, OK, here's the period. You don't say that, but you do it by varying your pitch and your volume and your tone. You give structure. And fundamentally important, you also convey enthusiasm. Yes.

AUDIENCE: On the other hand, I think in that lecture he offered [INAUDIBLE] [LOUDLY] he always speaks like this, [NORMAL VOLUME] which intimidated students a bit.

PROFESSOR: Yeah. Yeah. He maybe does it too much. In fact, he doesn't vary enough. It's sort of like the radio in *Spinal Tap*. It goes to 11, and it starts at 10. Because it's always loud. The amplifier's always loud. Yeah, I think he could actually have more dynamic range. So let's see. More--

In his defense-- Oh, yes. Go ahead.

AUDIENCE: Finish your thought.

PROFESSOR: OK. In his defense, you could say, well, when do you want to be really quiet? Well, that's when you're doing something that's less important. And he's actually such a good lecturer that he planned the lecture, I would say, quite well. He took out all the stuff that normally you would find in a lecture on this that's kind of dull.

For example, one thing that people do that's really kind of dull is they may derive the sinusoid as a solution. And how did he derive the sinusoid? Spray paint.

They did an experiment. He made it visible. He had a spring oscillating up and down with spray paint, so it was spraying on a big piece of paper. And then he pulled the piece of paper that way. So as the spring oscillated up and down and sprayed on the sheet of paper, it made a track, which you could see developing.

And then he just showed the class. He said, what does this look like? And they said, oh, it looks like a sinusoid. There you go. Now you skipped a whole bunch of painful math, otherwise, to make the guess.

And so either you guess it, or you do a bunch of derivation. He avoided both of those problems by actually just having the students see for themselves. In fact, he used the word see. I want to make you see what it is. So he got that.

He's taken out a lot of stuff where you would normally just try to pretend you weren't doing and speak really quietly. So that's maybe one explanation for why his dynamic range wasn't as big as it should be. But yeah, I think, generally, the point is right that he's so forceful and loud that it would be better if he just had a twice as much range.

AUDIENCE: Just an extra comment.

PROFESSOR: Yeah.

AUDIENCE: And this maybe be necessary in the old days when you don't have microphones in lectures. But when you have microphones, you can speak colloquially but still very clear to the students.

PROFESSOR: That's true. You have amplification. Yeah. And he did have a microphone, because he was being taped. But you're right. The habits of thought in presentation come from when we didn't have microphones. Yes.

AUDIENCE: The one thing I would change is at the very beginning he was talking about the test results.

PROFESSOR: Yeah.

AUDIENCE: And he said the test results were better, on average, than in previous years. And he said, oh, you're either a smart class or the test was too easy. Just generally, calling the students smart seems pretty alienating for the students who did poorly. And then even the kids who did well, there's pretty good evidence that saying "you're smart" rather than "you're working hard", the latter's much more effective.

PROFESSOR: Right. That's a really good point. Yeah, the test results discussion at the beginning. I always knew this lecture was a classic one, and this is the first time I watched it straight through, rather than just watching the sort of demonstration parts and the famous parts. And so it started off with this discussion about test results where he says all kinds of interesting things.

"You did very well on your first exam." That's word one in the lecture. "I was hoping for an average of about 75." So hoping, that's not a word I would have used.

I would hope for an average of 100. That's my hope. Maybe not what I expect, but my hope is 100. So by saying hope, he's saying, actually, it would be good if people got a lot of stuff wrong, like I'm hoping that people get 25% wrong. That could be interpreted as hoping that the students don't do great.

But then, on the other hand, the class average was 89. OK. So that's good news.

Now, as you say, he says, "either you are very smart, this is an exceptional class, or the exam was too easy." And he eventually concludes, no, the exam was taken by the instructor, so you guys are smart class. But even that he takes away by saying, "but time will tell whether you are indeed exceptionally smart or whether the exam was too easy."

So even the good news is tempered and taken partly back. And then even the good news itself, as you point out correctly, is not necessarily good for helping the students learn. So there's very interesting studies-- I wish I could remember the name. She's a psychology professor at Stanford, and she's done studies with kids.

What you do is you have the kids do a problem, and then you tell them either that they worked hard at it or that they were very smart. That's why they solved it. You tell Group A that, oh, yeah, you worked really hard at it. That's why you solved it. Group B, you say, oh, yeah, you solved it. You must be really smart. And then you see what kind of problems they try later.

Let's do Group B first, who are told you did it because you were smart. Later-- this is making an extreme of it, but this is the trend-- they don't want to solve hard problems. Because the only thing you can get out of solving a hard problem is you don't solve it, which then proves that you're actually not as smart as people though. So they want to solve easy problems.

The group that was told, oh, yeah, you did that because you worked really hard, they enjoy solving the problems. And they want to solve hard problems that they can't necessarily solve, because they can work on them. And some of them even say things like, oh, I love it when a problem's hard, which is a completely different attitude than the attitude of the people who are like, oh, I don't want to try anything.

Because I might fail, and then the truth about me will come out.

By making comments about people's intrinsic characteristics-- I made distinction earlier between intrinsic motivation and extrinsic motivation and how you really want to use intrinsic motivation. But there's the flip one, which is you don't want to make intrinsic comments about people, because that's very hard to change and very fixed. And that's what people are doing way too much of.

So whenever people can't solve things, it's because you didn't work hard enough, the conditions weren't right, you can call it making excuses, but it isn't. It's an optimistic way of looking at the world. And it's that optimism that people learn when they have control over the things that lead to problem-solving successfully or not. Yeah, I thought the opening was actually very bad in terms of that and actually set a kind of competitive, hierarchical tone, which I would have definitely avoided.

Other comments? Other things you noticed? Yeah.

AUDIENCE: He kind of oozed with passion about the subject. Usually, [INAUDIBLE] 5,000, he still seemed amazed that they worked.

PROFESSOR: Right. Right. Let me erase this guy. Right. He's shedding passion. He's oozing passion. I'm sure he's done the demo many, many times for every semester, no doubt. Yet he was still so excited.

For example, the ending, what did he say? They did 10 oscillations with Walter Lewin as the pendulum bob. And then they counted up to 10. So then he got to 10t with Walter Lewin, 45.6, plus or minus 0.1 seconds. And the prediction was 45.7, plus or minus 0.1, so it was right on the nose.

He said, "Physics works, I'm telling you. See you Monday." So he ends with enthusiasm. He is enthusiasm throughout, all the way through. Yeah, it is contagious. People did applaud, and I'm sure it wasn't just because it was being taped. They really were very pleased and amazed at the close agreement, even when he changed the pendulum bob from just the regular pendulum bob of a few kilograms to Walter Lewin of 70 kilograms or-- he's probably more-- probably 80 kilograms.

And throughout as well, doing the demonstrations, he was also very enthusiastic. And even sometimes he got lucky, and he even said so. But he said, fantastic agreement between theory and experiment. Yeah, so the enthusiasm, it transfers.

And in fact, our system, our brain is actually much better at picking up this kind of stuff than it is at picking up the Navier-Stokes equation and things like that. Let's call it an emotional highway. It goes in the emotional highway.

So I mentioned the experiment that you can do to test this. The experiment you do is you just go somewhere and you just smile at people. And now 30%, 40%, 50% of the class is smiling back already. You can't help it. Even though you know and I'm telling you I'm just doing this-- There's nothing actually funny that just happened right now. I'm just smiling, just because I'm a nice guy and I'm smiling, and I just wanted you to see if the experiment works-- you can't help it. So that tells you how powerful that emotional highway is.

It's not just for smiling. It's the oozing passion. Neurobiologically, that mechanism is starting to be understood. I'll write the mechanism down.

We have what are called mirror neurons. What mirror neurons do is they recreate the state of mind of other people in us. So that's why they're called mirror neurons. And they're innate. It seems that monkeys have them. We have them. There's nothing you can do about them. And they are actually probably the mechanism by which we become social creatures and which makes us social creatures.

So if people around us are unhappy, we feel unhappy. If people around us are happy, we feel happy. And these mirror neurons, their firing tendencies are partly set in young childhood. So if the people around you are happy in childhood, you'll have a much easier time just automatically being happy later. And if the people around you in childhood are really unhappy and your childhood's unhappy, you have to work much harder later to overcome that. So that's the importance of childhood and child upbringing.

But now these are there, and your students all have them, being people. So how you act and how you perform is going to affect them much more strongly than any equation you say. It's fundamentally important, again.

OK. Any other points? Yes.

AUDIENCE: Yeah. I was thinking about the use of the spray--

PROFESSOR: The spray paint can? Yeah.

AUDIENCE: Yes. And it wasn't until now that I actually understood why he did that. Because when I saw it, I was sort of thinking, why is he doing that? Or if he pulled the lever faster, it's going to look the same. I didn't get it at all. And now I see it was to guess the solution [INAUDIBLE].

And then I'm thinking, when I was taught the harmonic oscillator for the first time, that's an opportunity the professor used to actually teach how to solve, OK, this is the differential equation, and this is the solution for it. And now you know for the rest of your life. Because solving a differential equation by [INAUDIBLE], you're not always going to have an experiment to solve--

PROFESSOR: To show it.

AUDIENCE: Right. It's kind of cool. But I'm not quite sure what's the purpose.

PROFESSOR: OK. So what's the purpose? It could go here or here, the spray paint example. The normal way it's done is that you either just guess it outright, you say, well, we've seen that equation before-- we being the royal we-- the instructor's seen the equation before and says, use the sinusoid. The students have never seen it before and just have to take it on faith. Then you put in the sinusoid, and then you show that it solves the equation.

The other way you do it is you separate the equation. There's many techniques for solving that equation. One is you write it in terms of operators and factor the operators, but the freshman aren't really ready for that. So you can't really do that.

You're basically reduced to guessing, at least in the American curriculum.

Now what he's done is he's done an improvement on that. Instead of saying just by bold assertion, just outright authority saying, please guess this, he's saying, look, this is what it did. What do you think it is?

And then the students say, oh, it's a sinusoid. He says, OK, good. That justifies the guess, basically, that I was going to make anyway. So it improves on the standard method of guessing and just plugging in.

But you're right. Not always can you do that. So maybe the thing I would have done is, if I were him, I would have said, ah, this is going to avoid us just either guessing the solution or doing a whole big, long calculation.

And he does say that elsewhere when he talks about the zoo, when he wrote down the differential equations for the x motion and the y motion. He said, oh, that has a coupled nonlinear equation. It's hopeless. It looks like a zoo, and it is a zoo. So then he approximated it.

He was quite good at saying, look, there's some things you just don't want to do. And this would have been, I think, another spot to do that. He could have explained why he was going to do the experiment.

OK. Just one other point, I think, that wasn't mentioned so far. Oh, yeah. Yeah, he never erases what he's using. We'll talk about that more the next time when we talk about using chalk and slides. If you notice, he never erased anything he needed.

Now you could just call that chance. So an example of when he had stuff that he was using before. He had the differential equation, and then that was way up on some board. And then later, after doing the experiment with the spray paint, he came to x equals--

So now he had to calculate x and x dot, the derivative, and x double dot and then put it in. Well, as he was doing that, fortunately this equation was still there the whole time. It was just high up. So he never erased anything he needed later. And I was watching pretty carefully through the whole lecture. I think there was no time when that had happened.

And you could call that chance. Maybe if it happened once it would just be chance. But it's actually preparation.

So that's part of lecture preparation. What am I going to need? And how do I make sure that it's still visible? Or you can write it again. That's also fine. But how do I make it so that students don't have to remember it, flip back in their notes?

Because to them, this is a new equation. It's not just the equivalent of one pawn, one chunk. It's six or seven chunks. So you don't want to fill up their short-term memory trying to remember that. You want it visible somewhere. And that was also planning. Yes.

AUDIENCE: He calls tension a force.

PROFESSOR: Yeah, he did call tension a force. I was most upset about that. That is the standard way it's done, and all the physics courses I took as an undergraduate did the same thing. And I'm sure that's how I got confused about it. I'm sure most people are confused about it because of that. And until they do a few thought experiments or have to teach it and really sort through it, they won't figure out that it's actually not a force.

Now I'm sure Walter Lewin doesn't internally think of it as a force. He knows it behaves differently. But it's so easy to use this shorthand, and then the students, they don't have any other structure for it. They'll just think it does act like a force. It add vectors, but it doesn't.

Yeah. So that was, I thought, a dubious point. But it's standard, unfortunately. It's a good lesson that just because something's standard doesn't mean it's a good thing to do. Yep.

AUDIENCE: He used the big chalk and colors.

PROFESSOR: Yeah, big yeah. Right. Actually, if you need to order this chalk, it's called railroad crayon.

You want to be careful to get railroad crayon, because there is actually big chalk you can buy from, I don't know, variety stores. And that's for, for example, writing messages on sidewalks. And the problem with that is that has wax in it so that it stays against the rain. But that's not so good for the blackboard. It's much harder to get off.

Railroad crayon is designed to be removed easily. If you order railroad crayon, unfortunately it seems to come in boxes of 144. Maybe you can get a box of 72. So share it around. If you find a source with smaller amounts, let me know. But the ones we found were 144, a gross, one dozen dozen.

But yeah, he used railroad crayon, so it was very easy to see what he was doing. And he used colors. For example, forces were always read. And he used a consistent naming convention for that, so he wasn't throwing noise onto the system. Yeah.

AUDIENCE: This was mentioned before, but I think one important thing he did is that he created suspense by taking a risk. Because he repeated the full experiment in class. Because [INAUDIBLE].

PROFESSOR: He created suspense by taking a risk. So there was actually tension, not this kind of tension, but the good kind attention where people were involved in interested. Because he redid the experiment, and it could have come out not quite right. And amazingly, it did come out right.

And when it does, then the point he's trying to make it even more strongly reinforced about physics works. And that was his goal. That was one of his overall goals for the implicit. I don't know if he ever stated it, but one of his implicit goals, you can see, is to convince people that physics works. It's a way of understanding the world. And if you really believe that, well, you should be willing to put your money where your mouth is and do it yourself.

There's an another famous experiment-- I don't know if it's in Lewin's lectures-- where you want to show that energy is conserved. And the way you measure energy conservation is how far a pendulum swings. So now the way you do the experiment, you have some giant pendulum with a bowling ball or a cannon ball at the end hanging from the top of the physics lecture hall, which is about this high. And you release it from your nose, and you just stand there.

So if energy's really conserved, it's going to come just to where you released it and no farther, which is good because your nose is right there. A little farther would hurt. The problem-- this still doesn't show physics doesn't work, but it looks like it-- is that it's so tempting to give it a little push when you release it. And it's just hard not to do, because whenever you let go of things, you push a ball, you throw something in the laundry basket. So now you give it a little bit of push, and physics works.

So it comes back with exactly the same push, which wouldn't be a problem if it was a wiffleball or a tennis ball. But because it's a giant cannon ball and at the other end of it's your nose, it gives you a nice crunch right there. I would only do that expect if I'd practiced it and make sure I didn't push it. But even if you do push it, it too shows physics works. But yeah, he created suspense. Yes.

AUDIENCE: So how can people do this in other disciplines? In physics, you have weights and swinging pendulums and blocks.

PROFESSOR: How can you do it in other fields? Yeah, it's a good question. If you remember, the wood blocks-- this is physics, mechanical engineering-- there was also suspense. Because when I tap this one, and then everyone was dead silent before we tapped this one-- just for review-- because everyone wanted to know. So suspense was created.

And it's just like any sort of magic trick or performance. You have to prepare it. So it doesn't have to be that you bring something in. It helps. But, let's see, what else could you do it in?

Chemistry. In chemistry-- it helps to bring stuff in, no question-- you could bring in chemicals. What do you think is going to happen when I mix these two? Well, what do we know about this? What do we know about this?

What's going to happen when I drop a ball through this? Is this viscous? Is it not? What clues did you have? OK. Let's see if now that's consistent with how the thing behaves.

So it doesn't have to be pure physics. Though it does help to bring things in, and so you do want to make everything you have as visceral and as visualizable as possible. So that is a general transferable principal.

Let me write down four general principles that you can use in all lecture performance, which is basically everything you said here. The first one I'm going to write down is very neglected, but you've just mentioned it, which is the suspense and the timing. If you want evidence that timing really matters, just go watch *Romeo and Juliet* again, or read *Romeo and Juliet*. Just because they were slightly off in their timing, they all committed suicide, basically. That's probably the very, very, very, very CliffsNotes plot summary.

And another part about timing, if you want more evidence that timing really matters, try telling a joke and tell the punchline first. See how well that does. And even a small example of that, for stories too. Stories, you want to tell the important part later, and you want to give the introduction first. Again, remember the sentence structure here, which is that the thing with emphasis comes right at the end. If the thing you want to emphasize happened at the beginning, then your timing is off, and things will fall flat. Yes.

AUDIENCE: OK. But that's exactly contradictory to the way some people want their information laid out, which is tell me the most important thing, and then back up with all the details.

PROFESSOR: Yeah. OK. So that's a good comment, which is that it's opposite of how people say they want things. They want the most important stuff first and then the details. The way I square that circle is I don't want to give away punchlines. Oh, those are gone.

So suppose I'm starting a new unit, and we're going to do a unit on extreme cases. I don't want to give away the punchline, which is, oh, this problem is hard until you use extreme cases. So I say, forget the organization of the course that I told you about before, and we're just going to do an example and discuss it. Then we're going to look at what makes it really easy, and then the punchline is extreme cases.

OK. Now that we know the punchline, because we've done the example, now I'm very happy to say extreme cases. Let's use extreme cases here. And this whole unit is going to be about extreme cases. So now people still have the structure, but the very beginning of it, they're a little confused. And I like the confusion.

So that's part of this. In a play or in a movie, or you go to a movie, you're not even sure who are the main characters and what are they up to. And then it comes into focus soon but not right away. And part of that is to draw you in.

Yeah. I wouldn't begin a lecture by telling people everything that they need to know, because that's spoiling the timing. The beginning of the lecture is this kind of sacred moment when you want to draw everybody into the lecture. And the beginning of a course is doubly that much.

You want to draw people in, not tell them, oh, yeah, here are the rules on homework collaboration and blah, blah, blah, blah. You want to emphasize the important things first, and you want to use this to pull people in so that you can come to a punchline. The punchline doesn't have to be way at the end of the lecture or the end of the course. It can be soon, and you can have a lot of soon punchlines. But for each one, you need to build to it. Yes.

AUDIENCE: [INAUDIBLE]. When I did my referencing thing, the first slide had a list of goals that I wanted to make, because I thought that that was what we should be talking about in [INAUDIBLE] teaching. And then you asked, would you have included those when you started the real lecture?

PROFESSOR: Right.

AUDIENCE: And I said, I wouldn't. I would just plunge right into the material, because I was thinking along the line of what you're saying now. And then you said, no, I think it's actually good for the students to see it outlined what they're going to learn. And so that's actually [INAUDIBLE].

PROFESSOR: Yeah. That's right. I think what I would do is I would show them that goals-- Goals are OK, as long as you don't begin the lecture by saying, here are my goals, because that's that secret time you're taking away from. I would put the goals, say, on a side board, so they can see them all the time, or write the, just after you've done your punchline. Then put them all up.

AUDIENCE: So it's the second or third slide.

PROFESSOR: Yeah. That's right. Yeah. The very first slide is something interesting that doesn't necessarily seem like it's related to the class. And that's already a punchline. Oh, wow, this? We can understand this from the stuff in class? I want to know.

That's a drawing in. And then you get to the punchline, which is, yes, you can. And the goals are to see this all over and see these three principles that we just used and really understand them.

OK Another one be bold, so bold gestures. Bold gestures, voice, you'll see that all throughout Walter Lewin.

Another one, we've actually done, I would say, a lot more with it than you saw in the lecture, which is-- And the third one is you want to involve the audience by asking them questions, making your whole lecture interactive. So we've discussed, actually, many ways where the Lewin lecture could be improved in that direction.

And perhaps underlying everything, none of this really works unless there's principal four, which is that you have to care. You have to really, really love what you're doing and transmit that to the students. And then, all of these things become so much easier when you care. So those are the fundamental principles of lecture performing and, basically, planning around things like that.

And if I just had written those down in the beginning, it wouldn't have made sense.

But now you've seen many, many, many examples, and we've had many discussions about it that I wish you success in applying good timing, good bold gestures, strong gestures, and involving the audience, not just emotionally or cognitively but both, so that you provide long-lasting learning and interest in the subject that you love.

OK. If you could fill out the sheets for just one minute. And then we will have office hours. Actually, what we'll do is we'll meet right outside the door, and then we'll just go sit in the cafe area. And anyone who wants to get a bagel can also get a bagel, if you're interested.

Answers from Lecture 8 to questions generated in Lecture 7.

PROFESSOR: So first question was, a while ago I mentioned there was research saying that if you pay people for things they like doing then they start enjoying it less. Can I give you a reference for that? The reference for that is I actually put on the readings for next week, which is the political barriers to educational change session, one of the five readings-- they're all basically short-- is by Alfie Kohn, and it's about competition. And that's one of the areas he researches a lot.

I gave you one of the short articles by him to read. But his whole website as lots of different articles and references. He has a whole book on the whole subject called *No Contest*. I think the subtitle is *The Case Against Competition*.

So he goes through, I don't know, 100 or 200 studies about the effects of rewards on people's performance and interests. It's a totally fascinating book. And I think it just came out, or recently it has the second edition. But both editions are completely fine, so whichever one you can find, use that. And on his website, you'll find many articles on that theme, and I've given you one to read for next week.

OK. What is the Berkeley Physics Course? The Berkeley Physics Course-- This is interesting, because in the '60s there was a whole bunch of change. It was change in political systems and protests and legal systems, the Civil Rights Act. And there was also change in education. And that's probably not coincidence, that both changes were coupled or happened together.

There was the rise of the Free School Movement. There was also, in the university level, lots of different new curricula started. The Feynman Lectures on physics are a famous one that happened way over on the other side of the country and Caltech. And the Berkeley Physics Course happened also on the other side of the country.

There are several volumes in it. Probably the best known is Ed Purcell's *Electricity and Magnetism*. That's one of the classics of the Berkeley Physics Course.

There's a less well-known volume, which is, I think, even better, which is by Frank Crawford, and it's called *Waves*. The edition I have came in the back with a whole bunch of polarizers and toys you could use to actually do home experiments. And at the end of every chapter, there are home experiments. I think they're called "Kitchen Sink Experiments, and there were toys in the back in the little pocket that you could use for it. So if you find a used copy, those toys might not be there, but the book is still wonderful.

So those were two pieces of the Berkeley Physics Course, and they were about six volumes. And MIT had a whole set of books as well, I think by Tony French. So it was a whole time of ferment, and lots of changes happened, many of them good.

OK. How can you apply these lecture techniques that we talked about last time to laboratory or practical courses? This is actually an important topic, because many of us will do that? What's the right balance between teaching and lecturing and allowing students to solve the lab problems on their own, in other words, giving them enough rope to hang themselves?

Yeah. You do want to do that. You want to give people enough rope, but you also want to guide them, because you do know more than them. So I don't look at laboratory teaching, practical teaching as that different than lecture teaching. In some ways, it's easier, because one of the goals in lecture teaching is to show people that all the theory you're talking about actually has any relevance at all. And you have to try to work hard to bring stuff into the classroom and really show, yeah, look this really means something, the way Walter Lewin stood on the pendulum or sat on the pendulum himself and was the pendulum to really show, yes, this applies here.

In a laboratory practical class, if the practicals are at all interesting, that's automatically done for you. The last practical class I taught was the electronics practical for physics majors. At the end, they built an AM radio, a crystal radio. So that actually had a nice finale, and experiments before that built up to it.

The relevance was already done for me, but the problems the students had were the same as in regular lecture. They didn't understand the concepts. For example, what does a capacitor do? What does an inductor do? How do they work together? What is resonance?

So what I did for them is I gave them short little mini-lectures, two minutes three minutes on a conceptual question, and then sent them off working. Some of the other problems they had were, for example, they were really scared of oscilloscopes. They just got to the oscilloscope, and they thought, what the hell do I do with this thing?

So do I used an exercise that was done to me when I took the same class as an undergraduate, which was in your laboratory pair one person turns around and the other person randomizes the oscilloscope settings. They just turn all of dials to some random setting, and then the first person has to turn back and try to get some signal on the screen. So they have to figure out, OK, this voltage setting is crazy and get it back to a setting. And once you do that, you're no longer afraid of the oscilloscope.

Again, you can do in class problems that people work on together. You can give short little conceptual questions. So in a way, laboratory teaching isn't that different, provided that the laboratory isn't just a cookbook in the sense that, OK, do this, now measure that, now measure that, now measure that, now measure that. OK, write it all in your report. That's like lecturing just by saying now copy this down, now copy that down, now copy that down. So if you get away from that in lecturing and that in practical, then you get to the similarities between the two, and you can apply pretty much every lesson from here.

OK. Oh, yeah. Many of you pointed this out. The distillation of examples into principles that we did. So we looked at Walter Lewin's lecture number 10, and then we distilled from our discussion various principles of lecturing and performing. And many of you said, oh, yeah, that should have gone longer.

You liked the principles, but we should have done that for longer, which I think is a great sign. I think it's good that you guys are figuring out what could be improved. And I agree with you. I just got so carried away with all the interesting things you were finding that I didn't allocate enough time for the principles. So in my next life. But also, the point is everyone did appreciate having principles, so that's something to transfer for your own teaching.

OK. Let's see. What kind of interactive examples and demos can you do for a math class? I brought an example. They're in here. This was actually an example I did last week in my approximation class. And I enjoyed it so much I thought I'd show it to you too.

The principal I was teaching was the principle of easy cases, also known as extreme cases often. But I like this name better. And then I wanted to show that this principle applies across all kinds of areas. You can use it in math. You can use it in physics. You can use it in engineering.

And what we were trying to derive is the volume of a pyramid. So the original problem was this. You take a pyramid with a square base, and then you lop off some piece of the top. So the pyramid is B by B on the base and A by A square on the top, and it has height h. So what's the volume of that thing?

Well, you can guess a lot of it from easy cases. I won't go through all of that. But at some point, you need to work out in part of this guess the easy cases, use the easy case that A equals 0. In other words, you just have a regular square pyramid, like one of the Egyptian pyramids of Gaza. Giza? Giza, maybe. So then what's the volume?

OK. Well, volume's going to be proportional to the height. And then, it's got to have two more lengths here, so it's got to have B squared here. There's no A left. But then what goes here? What's the constant?

Well, this is actually where you can, yet again, use easy cases. So if you could find a special pyramid that could be combined into a shape whose volume you know, then you could actually figure out this constant. Because you don't know the volume of one pyramid, but if you could replicate it and then assemble them into a nice shape, you're home free.

What nice shape could make this into? And what pyramid shape do you need to be able to do that? So take a minute and think about that.

Anyone have an idea? What shape would you like to make?

AUDIENCE: Could you first make a rectangular cube and then cut it into six pieces?

PROFESSOR: OK. So you want to make a cube. Let's talk about how you're going to make this cube. You'd like to make the cube.

Now what part of the pyramid is going to become the face of the cube? Well, you have a square base, right? So it seems reasonable to expect that each pyramid's going to provide one face the cube. So you need six pyramids to make this cube.

Well, what shape should the pyramid have so that you can fit them into a cube? Hmm. How about that shape? So what's special about that shape? I'll put one here, and here's another one of them. Put that there. And here's another one.

OK. So here we go. Here's a cube with six of those pyramids. So what's special about the shape of the pyramid? What do you have to set in it? Yeah.

AUDIENCE: The height is half of the base line.

PROFESSOR: OK. The height is half the base. How do you know that?

AUDIENCE: Because the tips of the pyramids are [INAUDIBLE].

PROFESSOR: Right. So the tips touch like this. And this width has to equal either side of the square. That means, let's say, if h equals 1 and B equals 2, six times the volume is equal to the volume of the cube, which is 8. So the volume of one pyramid is 8/6 or 4/3.

h times b squared is 4, so you have to divide it by 3, and you're home free. So there's an example of a demonstration in math class that you can use. Now the point of it is that it's possible to imagine it in your head, but it is actually useful to see these things built into a cube. So even in math class you can do demonstrations.

What's my blackboard philosophy? I write big and sometimes place things fairly randomly. Is there a specific reason for this? But I like what you write down.

Yeah. My blackboard philosophy is not ideal, because of exactly that. I write large, which is good, but I do place things kind of randomly sometimes. And that's not ideal, so I try to improve that.

I don't necessarily have a reason for that. Don't actually copy that part of my blackboard style. But it's good that you're observing that and trying to criticize it.

OK. Let's see. How to practice blackboard work. We'll talk about that more today. But the basic simplest way that I've found is at the end of your session you just go to the back of the room and look at the blackboard and you just see was it organized, did it make sense, did I write a bunch of stuff in between, and just take a few notes down on that. And then you'll automatically be getting feedback that you can use to improve your blackboard work.

Oh, yeah. Several people pointed out they watched a different lecture than Walter Lewin's Lecture 10, because I said, oh, watch that one or another one. So next year, I actually am going to ask everyone to watch the same lecture, Lecture 10. That's a good suggestion.

OK. We talked about that. Oh, yeah, if you're an excellent lecturer and you are aware of the common problems, because you've taught the course many times before, and you try to address all the confusing parts, can you get away with not allowing students to ask questions in class and not asking students questions yourself? That's a very interesting question. Basically, can you move away from the interactive model I've been describing and recommending once you've done it enough and you know where the students' misconceptions are.

I thought about that, and the answer is really no. Because then you're reverting back to telling. Now you're telling them things they really do need to know. So instead of telling them a big long song and dance about the Atwood machine, which they don't really need to know, you're telling them about their misconceptions about F equals ma.

But the problem is just telling them that F equals ma, F equals mv, doesn't help them realize that. They really have to have some kind of cognitive conflict and struggle with it. So questioning, either you question them or them asking questions of you and formulating questions, is really about the only way to get them to struggle with it. Even then, you still have to do it. And the experience you have from teaching it many times means you'll be doing questions about useful, important material. That was quite an interesting question.

OK. What do I think of group assignments, balancing the advantages of collaboration with the fact that each individual may not encounter all the topics? I generally don't like them that much. I think if you design a course and you think there's a coherent set of material, everyone really should try to master that coherent set of material and not palm off half of it on one person in the group and the other person in the group.

The extreme of this kind is the graduate seminar where each graduate student gives a talk on one topic. And then they really learn that one topic, but they don't necessarily learn the other topics very well. So I don't like that very much. I think it's better to allow people to collaborate, but make sure everyone does their own assignment. And yeah, collaborate in groups, by all means, but please write up your own work as well.

What's the use of experiments in Walter Lewin's lecture? Was it to show the predictive power physics or its experimental character? It's not clear.

And in that case, wouldn't it be better if the students performed the experiments on their own or in a lab class? Aren't these demonstrations a waste of time that could be used to teach more theory? And aren't shows more appropriate for high school classes than for physics at MIT?

Well, I think, at the time, this was 1999, there was no laboratory with the introductory physics course. I need to get my history right, but I'm pretty sure that's right. There was no other way the students would ever see any application.

But the other main point of it is that it showed that the physics is real. Now I think it could be improved, as you suggested, by Lewin asking students questions about the experiments, trying to predict what would happen beforehand, for example. But the idea of bringing in objects is really a sound one.

I had a teacher at Caltech. He taught the waves and the nonlinear waves course. He always used to bring in a wave guide, which is, basically, a piece of metal in a tube-like shape. and he said he always did that because, otherwise, the mathematicians would think it's just a vessel function, because that's how it is in all the problems.

You see wave guide, you just start solving Laplace's equation with all these boundary conditions, you get Bessel function. And wave guide is just trigger for do Laplace's equation, get Bessel function. It has no physical meaning. So he would always bring in the wave guide so that you knew that it was a real object that you were analyzing.

And so in that way, Lewin, using the pendulum, showing that these things actually exist, avoids the trap that many students fall into, which is that symbols just have no meaning on their own. They're just stuff that goes on on the screen. So I think is really important that he does that.

OK. Working hard versus smart. How do you respond to people who tell you that they worked really hard but they still did poorly? I think, basically, the reason is that they didn't work smart. So what do students think working hard means? They generally think it means reading the book over and over again or trying really hard to do the problems but not reflecting.

The equivalent in playing chess is working hard at chess, people think, oh, that just means playing lots of chess games. But actually, that doesn't improve your chess ability. You have to analyze your chess games, reflect on them. And that's what we need to teach students how to do.

So whenever they do say that, I say, OK, well, what are you doing? Let's look at what you're doing and see if there are ways we can make it more reflective and less just going through the same stuff over and over again.

And then, final comment-- there are some more questions, but I'll leave it there for now-- while watching the 801 Walter Lewin lecture, I was surprised how much I was able to find wrong with it, even though he's a great lecturer. That goes to show how much we've learned so far in this class, which I thought was a very nice comment.

I'm glad. And I hope people did draw that conclusion. From all this stuff that you found to improve that lecture means you have actually learned a lot, either in this class or elsewhere, and you could actually make really excellent lecturers, really powerful, constructive lecturers yourself.