Physics Seminar

February 18, 2019

>>DR. GARRISON: Can I have everyone's attention? I want to get started. You guys may have noticed, if you look at the web site, that we don't have a biography for the speaker today. I've known Evan for a while, so I'm not going to let him get away with that.

So I want to introduce our speaker today. This is Evan Richards. This guy is incredibly impressive. He is one of the people who has been helping out with this transition of the physics program over the last few years. You know, as you guys know a few years ago, UH Clear Lake was just an upper level institution. We didn't teach any freshman or sophomore level courses and we didn't teach a lot of service courses, which is now a big part of the program and it's a big part of a lot of physics programs.

One of the challenges is that when you go from teaching physics majors to non-physics majors, there's a lot involved and there's a lot of things to learn. So what happened was when we had to go through that transition, we turned to Evan to teach us. He is a professor at Lee College. He's been there about --

>>DR. RICHARDS: About ten years.

>>DR. GARRISON: -- ten years now and he is an expert at Physics Education Research. This is actually what he studied for his Ph.D. in physics and, you know, like I said, he is pretty much the master at this. And one things he's doing now is he's teaching us how to utilize this active learning lab we have down the hall. And in a lot of ways we would not have even asked for an active learning room if it hadn't been for Evan.

>>DR. RICHARDS: So you can blame me for it, right?

>>DR. GARRISON: So I guess with that I'll turn it over to Evan and after the presentation I have some papers to hand back to you guys, and also if you guys could give me your papers for today after we're done. So just don't leave right away.

>>DR. RICHARDS: Thank you very much. I appreciate it. So let's kick things off. Hopefully everybody picked up one of those handouts because being a physics education researcher, I'm not a big believer in just talking at you for the whole hour or two. I'm going to get you involved doing something here as we go through this. So, first off, Physics Education Research -- last time I was here was years ago where i gave an old review of what PER actually is because not everybody knows too much about it. It's a rather unusual field in that it's fairly young as compared to several of the other research fields that are out there. And so turns out I'm one of only a handful of physicists in Texas who have actually graduated out of a PER group for my Ph.D. So in many ways, I'm very weird. And so today I want to give you just a quick taste of PER, give you a brief

overview of it, but then I want to dive right in to a particular branch of research within PER -- misconceptions.

>>DR. GARRISON: Let me check something real quick.

>>DR. RICHARDS: Sure. That's all right. Looks like we've got signal loss, huh?

>>DR. GARRISON: Just making sure she's got captioning rights, and she does.

>>DR. RICHARDS: Whoa, look at that. That's a fun effect.

>>DR. GARRISON: There you go.

>>DR. RICHARDS: Thank you. All right. So I'll give you a quick hit on what PER actually is, and then we'll dive into this particular branch of research. All right. So first off, PER. Think about physics itself, the scope of it. It's pretty big, isn't it? I mean, physicists look at everything from the very big, stars and galaxies, to of course the very small, the world of quantum mechanics there. And in fact, if you're not familiar with it, the photo, the first one that popped up, Hubble Deep Space Field. Really important in astronomy. Check it out sometime.   It's got a great story behind it.

In any case, there are challenges to each of these parts of the spectrum, the very big to the very small. And yet there are certain challenges that pup up in PER that a particle physicist doesn't have to worry about or that an astrophysicist doesn't have to worry about. For example, a star does not have a bad day at school. Another good example is, a hydrogen atom does not break up with their partner and is having a really bad day.

That stuff doesn't happen in most fields of research. And yet in the world of PER, what we study is the human brain. And in particular, how do people learn physics?

And so the world that we are in is a bit more fuzzy. I mean, quantum mechanics is fuzzy enough when you get down to it, but imagine the world of the human brain that has all these added layers of complications in it. That is the world I have studied, trying to understand how the human brain works and in particular how the human brain learns physics and stores physics and applies physics later on.

And so in many ways, Physics Education Research is a conglomeration of a lot of fields. So in my time as a grad student, yes, I studied a lot of physics. But I also studied neuroscience. I studied human cognition, education research, psychology, weaving all those together to become the very strange person I am today. And so PER, it's a very broad field in that it does bring in a lot of disciplines and we weave them together in order to apply them specifically to how people learn and understand physics.

The other side of PER is the fact that it turns out that years ago, when it started, it came up out of physics programs. You know, people asked me, why would it not come out of an education research program? Why is it coming out of physics in particular? Well the answer to that is frankly physicists do not trust anybody else to teach physics, right? We believe in our own ability to convey the material. We don't trust anybody else to do it right.

And so ultimately when the early pioneers of PER were beginning to dive into this, beginning to study human cognition, neuroscience and so on, it was quickly recognized that only physicists are the ones who are in a good position to study how people learn and apply physics. In fact, I always like to say I would be a terrible biology education researcher. Sure I know the psychology side, I know the neuroscience side. I have no clue what the misconceptions are in biology. In fact, I would probably have a lot of them myself. Right? So you want a content expert leading the charge.

And that's ultimately how PER got started. It was a group of physicists recognizing this was a problem and also understanding that, you know, as a physicist we do learn some rather sophisticated research methodologies. Why not apply it to the world of education research and bring that expertise in, our own twist to it? And ultimately that's where PER came from.

So let me give you a sense of one branch of research within PER and that is misconceptions. You know people walk in my classroom all the time, they have a certain set of ideas on how the universe works. Some of them are pretty good. Other not so much. So we do a lot of work over the course of the semester to make sure that by the time my students leave, I've replaced old ideas with more powerful ones.

And so tonight I'd like to talk about the different types of misconceptions that are out there and ways you might be able to address them. Okay? Because let's face it, a lot of folks in here, particularly my grad students, you graduate, you go on. Odds are you will probably be teaching in some capacity. Right? Yes, you have perhaps a lot of research in your future, but you will probably have a bit of teaching in your future, as well. So some of these strategies are, well, for your consideration as you progress forward in your own careers.

So let's dive in. Let's talk about what I would call the shallowest level of misconceptions and that is just simply the facts. And so as it turns out, these are the easiest to impact. These are the most straightforward to affect, the surface level issues.

And so let me give you an example of some of these. First off, I have a question for you. Okay? And so we're going to vote on what you think the answer is to this. No fair getting on your phones or laptops to look up the answers. I'm watching.

So we're going to vote on this, and here's how we're going to vote. We've got four options. We're going to hold up the hands, not high because everybody will see how you've voted. But kind of low right here -- one, two, three, and four. And I'm kind of curious to see what everyone thinks.

So where do you get coffee from? One, two, three, or four? All right. I'm seeing a variety of answers out there. Believe it or not, actually one of the least popular answers. It's the seeds of that fruit right there, coffee cherries. You roast them, process them, grind them up and that's where you get the coffee from.

Let's try another one. Again, can't look at your phones. No fair getting on laptops. What's the capital of Australia? Gut reaction, what do you think? All right, there we go. I'm seeing a variety of choices. This is fun. Those of you who went with two, Canberra, you got it. Yeah, there it is.

All right. So how do you fix that? These are basic facts, aren't they? In other words, there's nothing advanced here that we're talking about. It is literally what is the name of this? Well you fix it just by telling them, right? There's nothing fancy needed here. These are very shallow misconceptions that are easy to dig up. You don't need to go through any advanced mechanizations to extract those and replace them with something else.

All right. Let's get to the more interesting ones, the deeper misconceptions. So, we're going to dig a little deeper and head into what I would call the medium level misconceptions. These are a bit more interesting, and these are far harder to dig out. In fact, research shows that they have had students who have been through a complete set of physics instructions as an undergraduate and even after a few years of physics courses, some of these are still there. Yeah, they're really hard to dig out. In fact, even after you see repeated exposure to these topics, sometimes they just don't go away. It is super annoying. So we'll talk a little bit about a few of these tonight, as well.

So you'll see they come in two broad categories. It's common sense, of course it must be true. And then you've got what I call resource activation. And that is -- and you'll see this idea in the literature a lot. What happens is is people are hardwired to have certain preconceived notions that we use as building blocks to put together our reasoning. And these in many ways have been characterized as very primitive notions. And you'll understand what I mean by that as we get deeper into this. But these building blocks, these very basic, fundamental notions that seem to be common to the human experience, well, they show up a lot in the literature. They show up a lot in the research.

I've given you just four examples here. They call them different names, but it's really the same idea. These are fundamental, primitive, basic ideas that humans seem to have and we put them together, we piece them together to then form our answer to various questions. Sometimes these are useful. Sometimes they're productive. Other times, not so much. So we'll talk a little bit about how you can direct these in a productive way, in a more positive ways.

So let's start with naive notions. So first off, here's some classic examples from physics. All right? One of them is the great heavier falls faster idea. Ooh, that's that one is a tough one to get rid of, isn't it?

What's really irritating about that is it's one of the easiest to prove wrong. Just take a book, a piece of paper, crumpled paper really small, and drop them together -- they fall together. Take a grape and grapefruit, drop them together, they still fall together. No matter what you do here, as long as you minimize air resistance, they fall together. In fact, we even know about how fast they fall. Near to the Earth, it's about 9.8 meters per second squared, right?

So this idea pops up a lot. In fact, you could go back to the writings of ancient Greece and see ideas like this popping up. Humanity has had these ideas for a long time. Needless to say, they're not so easy to dig out. Because, quote, common sense -- until you actually test it. Oh my gosh, it's not working. I mean, it took us all the way to Galileo to start figuring out some of these things were wrong. It's kind of incredible.

One of the things I like to tell my physics one students by the end of the semester after we've torn apart some of these ideas is, consider this, it took us thousands of years to understand why these are wrong. Can you imagine going through one semester of physics and then being able to say you have been able to advance your understanding of the universe by several thousand years? How many times in your life can you actually say that? Yet I tell my physics students, we just did it. Some amazing things by the end of the semester.

Motion implies force. If something moves, it's got to have a force on it. Oh man, that one is brutal. Trying to dig that one up, it's tough. So I've given you some examples from physics. But, hey, we all are familiar with physics here tonight. Let me give you something from another field. How about botany?

So think about trees. You're out in a forest. You see these giant trees all over the place. I still remember driving through the great Redwoods out in California when I was really young kid. I remember how about those trees were. They were monsters. So the question is this: Where does it come from? Trees have a lot of mass. Where does all that mass come from?

Yet again, we get to vote. I'd like to map out what your ideas are here. Where does all that mass come from? All right. Oh, boy, I'm seeing some real group think here. Some very popular answers. All right. There we go. I will tell you, a few people got it right. This one is tough. I've got to admit, I got tripped up on this one myself. I'm embarrassed to say I should have saw it right out of the gate. When you hear the answer you're, like, oh, yeah. That is obvious, isn't it? But this one is tough.

Let me tell you the answer by showing you this video clip. You see, this is a famous question in botany. Turns out, this was asked of a bunch of Harvard graduates. In fact, they caught them on graduation day. You see them all dressed up in their regalia and they asked them that question. Watch what happens next. Here we go.

Well, maybe here we go. You know, funny enough it was working earlier. That's weird. I wonder if the sound is being routed to the software instead of out to here. Such a good video, too. Such a good one.

So I get to hold you in suspense a little longer. That's right, we're all on the edge of our seats. Which one is it? By the way, you can turn to your neighbor. Try to convince them you're right. Check with the people around you. It's called peer instruction. Yeah.

(Laughter).

Worst case, I can do without it.

>>DR. GARRISON: Well, try it and see. I don't know why the audio doesn't work.

>>DR. RICHARDS: That's weird.

Okay. I may just have to tell you the answer on this one. It's tragic, because in the video they hand the graduates a seed and they say from that seed you get a big tree out of that, right? In a moment you'll see them hand them part of the tree. They say, how do you go from this itty bitty seed to this big old tree? And you get to see some biologists talking. Sadly enough you can't hear them, what they're saying.

But the bottom line is this: Those of you who went with air, you got it. Think about photosynthesis. What's going on there, right? That's where the tree is getting its energy. All that carbon? Now you know where it's coming from, building up in that tree, creating all that mass. And yet what primitive notion was I keying off here? See, a lot of people think in terms of it's got to be something more solid than that. Maybe the soil. That seems to be one of the obvious answers. Not many people picked that, I thought that was interesting. A lot of people go with water. That is a little more tangible, isn't it? So it feels rights.

In other words the primitive notion that we're talking about here is you don't get something from nothing, right? Of course you can go back to concepts in physics like what is going on during the early -- not even days, but early moments of the big bang theory -- the big bang? What happened after that? Quote, you can't get something from nothing. See how this can lead you down some very dangerous paths if you misapply these particular ideas there?

All right. Another good example from physics. Classic one. That's this: Big truck hits small car, who feels the bigger force? Right? We've probably all seen this. There's no shock here about what's happening, and yet you could probably remember how you felt about that question before you learned all this fabulous physics, right? Didn't it feel right to say, well, gee, the car felt a bigger force. The truck was the one that hit harder. My gosh, the car goes flying away. Right? It feels more right. Bigger is more. See, that's another primitive notion there.

The question is, how can we adapt that in a more productive light? If you talk in terms of inertia, that's not such a bad idea, is it? The truck has a lot more inertia than the car does. How can you twist this around and talk in terms of well, what is really happening here? Well, then inertia, resistance to changes in motion. You get into the fact the truck's got a lot more inertia so it resists that change a lot better. So what happens? It doesn't have much acceleration does it, compared to the car?

So when students say, my gosh, that car feels a huge force because look at it go flying away. What they're really activating is not necessarily the wrong picture. They might have the right idea in mind, but they're using the wrong words to describe it. They're attributing the change to the word "force" whereas if they replace that with "acceleration," it's not such a bad thing.

This is called resource theory. The idea is they may be activating the right image, the right idea; but they're activating the wrong resources to describe it. That's part of the challenge of teaching is are you in a scenario where a student perhaps has the right idea, they just don't know how to describe it properly. Or do you have a situation where the student is genuinely off the beaten path and going down a dead end, ultimately? That's part of the challenge of teaching is how do you sort these out? All right.

The other thing that this highlights is the difference between what I call a surface level misconception versus a algorithmic misconception and that is a level one versus a level two. Level one, very shallow. Level two, a bit deeper.

Level one -- I've seen this happen before. A student will correctly say, oh, my goodness, the forces, they're equal but opposite because of first law. Okay. Well, at least they said forces were equal but opposite. Just used the wrong law. So what is that? That's surface level. They're using the wrong label here. We've got to fix that fact. Right?

But a student who then says, no, the forces aren't equal but opposite. The truck hits harder. See, that's a deeper level misconception. That's no longer a level one. That's now down to a level two. There's a fundamental flaw in their thought process that we have to fix.

So this is what we're getting at here. How do you differentiate between those two levels of misconceptions? Because it will affect how you address them. We already talked about how you address level one. But how do you address level two? Like I said, these are a bigger challenge to root out.

So let's talk about that. First off, I mentioned primitive ideas. Those primitive building blocks. Now, having primitive ideas -- closer is more, right? You can't get something from nothing -- well, they're not necessarily bad.

I mean, consider this: These ideas helped us survive. Right? Particularly in the early days. Think about this. A herd of buffalo is coming at you. As they get closer, they will get bigger. Bigger is more. You might want to get out of the way. Right? Good survival instinct, isn't it? You've got a fire there, you get closer to the fire. Oh, it's hot. Closer is more.

These ideas, not necessarily bad things. We've just got to make sure they're being applied in the right way.

So what are some of these ideas? Again they're called different things in the literature. But you see these same themes pop up time and time again. Now, these are a few. There's more out there. If you're really interested, I can give you some great 70-page papers to read through that talk about these. All right? There is truly an enormous body of work about these. We've studied this for a very long time.

Giving you some examples up here. Right? So again, how do you address these? It's not so simple as saying, oh, well, this is what the answer should be. Like we could do with a level one. These will stick around if that's all you do. We have to take it to the next level. Bada-bing, bada-boom.

Here are two strategies on how you actually address these deeper misconceptions. Okay? So I want to go into detail about each of them one at a time. Let's talk about guided inquiry learning because there are a lot of misconceptions about it. Yeah, couldn't resist. There are a lot of misconceptions about it because folks who have heard about guided inquiry who say, oh, it doesn't work, it's nonsense -- well, generally they have the wrong idea about what it is.

There's an idea out there that guided inquiry it means I'm going to throw some stuff, some equipment at you and say go learn something. I'll be back in half an hour. And I leave. These are called open-ended, open-goal-based activities. Yeah, that's not what I'm talking about. In fact, I want to give you an example of a guided inquiry activity that I use in my classes. That's what the handouts are for. As promised, I get you involved here tonight.

Turns out one of the classes I teach is a physical science class. Now, this is a basic survey course where we don't get deep into the mathematical analysis. It's mainly a survey of ideas spread across a broad range of physical science topics. We have geology, astronomy, of course physics is on the list -- my favorite -- chemistry, the list goes on and on. So it's a broad survey course covering a wide range of topics, wide range of ideas.

Because we cover such a wide range, we can't go super deep in anything because you've only got so much time in a semester, right? I generally see a lot of aspiring elementary school teachers in this class. I see some middle school teachers in this class. Mostly built for education majors. In fact, as part of the class I get into the Physics Education Research reforms with them as an added bonus. It's a fun class to teach.

One of the things we do on the very first day is the activity you have in your hands. So this is the challenge. You see, most people when they give you a game to play, they tell you what the game board is and then they give you all the pieces and tell you the rules and say, go play.

I'm not going to do that. I will give you the game board and the game pieces here. The idea is imagine -- so you have to use your imagination here -- you have a whole pile of tokens. So three different colors -- red, green, and blue. And each player can pull from these pile of tokens. So you've got those three big piles, all different colors.

And on the back of the game board I've given you several different games -- in fact, there are six games total -- of two players playing this game. And I've told you what moves they made. You can tell where they put each of these red, blue, and green tokens on the game board. So instead of telling you the rules, I'm giving you the moves they made.

Here's your challenge. What are the rules of the game? These are called reverse games, by the way. I got a whole booklet of these. So take some time. Analyze the games that were played. See if you can figure out what the rules actually were.

And, by the way, I love group work. If you're sitting near somebody, two heads are better than one. Feel free to collaborate. I encourage that. See what you can come up with. What are the rules of this game?

This is one of the trickier ones out of the booklet.

>>STUDENT: (Inaudible).

>>DR. RICHARDS: That was how I figured it out. You saw exactly the right thing. The moment I saw that and I traced back the moves, I went, oh, there it was. Yes, that is the secret. Had they not said that, I would have been in trouble in figuring this one out. I love the fact they use the primary colors. You're hinting at what I want you to see -- I love that terminology. That's good.

(Laughter)

Let me give you a little hint. This one is tricky, I admit. I gave you one of the more entertaining ones out of the pile there. Take a look at the back of that first page where they give you the four games. Let me tell you what unlocked it for me. Now, there are four games back there and yet one of those games ends differently than all the others. Which game on there really stands out to you on how it ends?

>>STUDENT: The second game.

>>DR. RICHARDS: Yeah, that one on the upper right, isn't it? Yeah, they didn't win. They lost. You know, that's the only game where somebody actually lost as opposed to won? Now, think about why you lose a game. Wouldn't it be because you make an illegal move? Food for thought. Why did player one lose? That's what unlocked it for me.

Trying to flip it over. There we go. It's kind of fuzzy, but I guess it'll work.

Okay. Let's talk about this one. Now, I can see that some groups have done a pretty good job sorting it out. It's tough. It is tough.

So I know before I move on, everyone is like, you have to tell us what the rules are, right? All right. Let me put a disclaimer out there. First off, I don't have an answer key to these; but I'll tell you what I came up with. So this is what I think the rules actually are here.

So what stood out for me, like I said, is the fact that player one lost here instead of won, right? What broke the pattern that was going on? It's this last move. You see, if you trace through where they were putting the game tokens on these, you'll see that certain numbers here are connected by these nodes, aren't they? And in every single move until you got to that one, every one of those nodes had a different color attached to it. It was red, green, blue. Red, green, blue. Until that one player put two blues on a node. Oh, for shame.

So what's the rules of the game? You can only place a color if it's a unique token off that node. You can't put two blues, but you could do red, blue, green off the node. You can't put two reds or two greens, either. It's got to be three unique colors off the node. And whoever makes the last legal move wins. Or you immediately lose if you make an illegal move. That's what I got out of the game there.

By the way, did you notice the choice of colors they used? Red, green blue? Primary colors? Isn't that beautiful? Yeah, you can tell it was written by a scientist.

A couple of things I want to highlight here. Did you notice what I was doing while everybody was working on this? Its something I do on a regular basis in the active learning lab. I wasn't just standing up here staring, right? No. I was walking around, wasn't I? Listening in. You see, part of the power of the studio classroom where everybody is at tables instead of in a giant lecture hall is everybody talks to each other. They explain, here's what I think is going on. And I listen to every word.

And the best part about that is as an instructor, getting a window into a student's mind on this is what I think is gold. It's beautiful. And it happens naturally when you work in a team. Right? You automatically explain what you're thinking to your teammates. They explain what they're thinking back to you. And I listen the whole time. Right?

That is gold to an instructor to pull that kind of information out. So instead of just reading body language -- oh, they look confused or I think they're catching onto this -- I know for sure because you're talking about it. Right? So part of the power of that active learning classroom next door is that you are at tables working in teams on stuff instead of in this giant lecture hall where I'm trying to read body language and see, okay, are we locking in or not? Actually I know whether you're locking in on it or not.

That's a separate issue, though. Wanted to ask you to do this in particular. Well, think about how you approached it. Now, actually I'm very lucky tonight because I'm giving a talk to a bunch of folks who are deep into science and you kind of naturally default into this. But even those who claim "I am not a science person" make the same approach, which is perfect because it's what I wanted you to see.

Think about what you did at first. I propose that a rule is this -- we'll call that a hypothesis. Right? Then what'd you do next? Were there any moves in the game where that didn't work? In other words you're trying to falsify your hypothesis, aren't you? And gee, what happened at the end? I couldn't tear it down. Must be a pretty good idea. In other words, you drew a conclusion. Hopefully this sounds familiar to everybody in here. Scientific method? Right?

This is how I teach it. Notice I don't tell my students up front I'm about to teach you the scientific method. No, I don't do that. I say, here's a game. Figure out the rules. And people come about it naturally. Right? This is guided inquiry. I don't tell you up front what I want you to learn. Instead of I give you a task, I put you in a situation where you naturally get to what I wanted you to learn. You see?

Also notice what I did here. A really well-designed guided inquiry task is not wide open-ended. That's why it's called guided inquiry. In fact, I put you in a scenario where I restricted your search space. Didn't I? See, I didn't just say figure something out and leave. I gave you a very specific task, didn't I? Analyze this game in particular. Analyze these moves in particular. So that way you're not wandering off into the wilderness and I hope you stumble across what I wanted you to see. I'm forcing you down that path.

Let me give you another example of this. One of the labs I like to do is a Newton's third law lab where I give you a track to mess with and two carts and we put some force probes on them. We put some motion detecters on the sides of the track so we can measure, well, when the carts bump into each other, we can measure the force that each experiences. We can look at their accelerations with the motion detectors pointing at them, right? And we bump the carts into each other.

And what I tell my students is this: Come up with a scenario with these carts -- and oh, by the way, here are some masses that might be handy. Come up with a scenario where when the carts bump into each other, they have the same size acceleration. That's not too hard. Now make the accelerations different sizes. Again, not too hard. Now make the forces the same size. They can do whatever they want. Can't go wrong there.

Then I give them the zinger. Make the forces different sizes. That drives them nuts. I let them suffer on that a while. And by the end of it, they say I can't do it. I can't make it happen. And I go exactly. Don't forget that. You just learned Newton's third law. And people look at me, like, you asked me to do something impossible? Come on, Dr. Richards. What are you doing to me? And I say, yes, but you will never forget it.

And it's true. In fact, I get on course evaluations at the end students saying, "Remember the stupid lab you had us do at the beginning? I still haven't stopped thinking that." And I went, yes, we learned something. You will never forget Newton's third law for the rest of your life. Very powerful way to dig out a medium level misconception. Right? A guided inquiry.

By the way, the other method, predict-confront-resolve. Shows up quite a bit, too. In fact, it's a slightly older method in many ways. The idea is this: So you study a phenomenon. Maybe you're taking some data, running an experiment. But before you do the experiment, I ask you to make a prediction. But I don't just ask you to say the prediction. You have to write it down.

Why do I ask people to write down what's going to happen? Because, you see, the brain is a tricky thing. Here's where some of the psychology comes in. The train is a tricky thing. You could just say out loud, yes, I think this is going to happen. And then something else happens and you know what the brain will do nine times out of ten? It will be absolutely convinced, no, I actually predicated this other thing that you saw happen. I was right all alone. And you will genuinely believe that, even though earlier you just said this other thing is going to happen. The brain is very sneaky about that. So by writing it down, you are committing yourself to this is what I was thinking before I actually saw the answer. Right?

That's the important bit about actually writing it down. Research has shown this does have an impact. I make students commit to the prediction before we actually try it. And as my students will tell you, yes, he's really bad about that. Particularly when I'm teaching lab. They will say, oh, my gosh, he makes us write down every prediction. Yes, you have to commit to it and only afterwards can you actually try it out. That's the idea.

So ultimately what are we doing here? What do both methods really key off of? Well, the answer to that is the fact that I am making students face their own ideas. And ultimately, I am asking them to generate their own ideas on how to resolve any misconceptions. Right? I am not telling them, resolve it by doing this. Yeah, they're going to forget about that five minutes later. I'm making it face their own ideas.

Because here's the reality: People believe their own ideas far more than they'll believe what some yahoo like me says. Right? In fact, they've done research on this where they actually handed a standardized assessment instrument to a group of students and they asked them, fill it out with what you believe the answers are. And they did.

Then they gave them the same instrument a little while later and said, okay, pretend you are a physicist. Answer these questions the way a physicist would. And they did. And they gave different answers on what they believed a physicist would answer versus what they actually believe to be true. And get this: The answers they gave when you asked them give me the physicist answers tended to be the right ones. And the ones they believed in, actually believed in, tended to be the wrong ones. Yeah. It's incredible.

You know, you get data like this where you get this sense of the moment my students leave the classroom all of the sudden, core dump. Yeah, that's just what the professor wants to hear. I don't really believe it. Obviously I don't want that to happen in my classes. I want my students to leave going, yeah, actually this stuff works. Right? He's not just teaching me nonsense here. This is the real thing. This is actually how the universe works.

That's what I'm aiming for. That's what these methods ultimately target. They ultimately dig out these misconceptions and replace them with for more productive ideas. Because again, people believe their own ideas far more than they will ever believe what someone like me says. I mean, I'm the professor of the class. I'm just grading papers. What do I know? People believe themselves more than anything else.

So that's the secret. Can you get people thinking about this in their own way? Because here's the other thing about the human brain, how it's wired. See, neuroscience actually tells us how people store memories in their brain. It's through connections in the cells in the brain called neurons. They extend out these tentacle-like things called dendrites to each other and they send signals, these dendrites. And they talk to each other by sending these signals out. It's in the patterns of these dendrites, these connections that are built up is how information is encoded and stored. But here's the sneaky thing about the human brain -- everyone is unique.

In other words, memories are relational to each other. You know, ever one of those times where -- in fact, to this day, this happens to me. I walk by a bakery and I get the smell of fresh baked pies hitting me and I'm instantly thinking of my grandmother who would make awesome pies. And I instantly get thoughts of her kitchen every time I smell fresh-baked pies. That triggered those other memories.

What's really going on is that activated those connections in my neurons to go back to my earlier coded memories. And all of a sudden by activating these neurons, these are activated as well because they are connected to each other. And the way I stored information, like Newton's laws for example, they are encoded in these unique connections, unique memories that I personally have. Which means everyone in here has encoded that in their own unique ways using your own unique memories and experiences.

In many ways, the way we've wired up the same piece of information is unique as a thumbprint or as the retinal pattern on the back of your eye. Our brains are very uniquely wired. So even if we somehow developed the technology to take the patterns in my brain and directly copy them onto somebody else's brain, that doesn't necessarily mean it will make any sense to them. Because, again, the way each and every on of you store information will be different than the way anyone else stores information.

This is what I think, so I am speculating here. But this is what I think is at the heart of the problem. If I tell you directly, this is the way I think about it, that's all well and good. But more importantly, how do you think about it? Right? That's how you're going to store it and that's how you're going to remember it later on. That's what these methods get at, having you store it in a productive way, a more powerful way, but in your way, not mine. Okay? That's where I think the real power lies.

All right. I saved the best for last. The deep level misconceptions. Oh, we haven't even gotten started yet. Yes, the deep ones. These are the ones that are frankly the toughest, most brutal ones to dig out. They're really hard to dislodge. I mean the medium level ones are tough enough. But when you get down to these beasts, they are really hard to uproot. Okay? And so let's talk about those two categories I have up there. Your belief in what you are, your self-identity, as well as your beliefs about the universe in general.

All right. Let's talk identity first. Now, this doesn't happen too much in my university physics courses but it does happen in the lower level physics courses I teach like that physical science class I mentioned earlier where the people in there, they're not physics majors. Which breaks my heart, but they're not. These are folks in other majors. A wide range of majors. I get fine arts in there. I get architecture -- well, not so much architecture. I get fine arts in there. I get the liberal arts in there. I get a ton of education majors in there. Right?

These are not folks who need to understand how to integrate over velocity to get displacement, right? That's not what they're there for. No, they're here just to learn the basic ideas. What's going on? Can I describe in words what's happening here? Can I use the right words to describe what's happening here? In many ways, it's vocabulary. So I get a lot of people walking into my classroom saying I'm not a science person, I'm here because I have to be. This is the only science that fit on my schedule and I'm scared to death because it's got a P-H-Y-S in front of it. Oh my gosh, it must be terrible. I see it as a challenge. As you can see, challenge accepted. Right?

In fact, it was a year ago I had an education major in my class. First day of class, I kid you not, the students comes to me and says I absolutely hate physics. That's how we opened up. I went, hmm, okay. And I had it in high school. It was a terrible experience and I'm here because it was the only science at the entire college that fit in my schedule.

And I said, all right, all I ask is that you give me an open mind. All right? Give me a chance to convert you.

You know what's funny? By the end of the semester, it was about a week out from finals, she came to me and said I can't believe I'm going to ask this but I want to be a science teacher. What level should I be looking at to teach this stuff? And I went, yes, converted her. Boom! Talk about a 180 difference. Right? Going from "I hate this stuff" to "I want to teach this stuff." It don't get much better than that.

And it happens a lot. Over the last several years that I've been teaching this course -- I developed this course about three years ago now. And I've been running it fairly steady for three years. And it happens on a pretty regular basis where I get -- although that was the most extreme case, where they just outright said, "I hate physics." I haven't had too many people say that. But I have a fair amount say I'm not a science person. I am terible at science. And I'm like, hmm, we've got to draw that out.

Because the reality is this: If you really drill into what is the fundamental characteristic that got us all interested in science? What is the one thing that made us go, yeah, that's something I want to try out? Isn't it curiosity? Right? A desire to understand what's happening out there?

And the thing is I'm willing to bet every single person, even "I'm not a science person," has a curiosity built into them. It's part of the human condition. Right? We are naturally curious about things. And I tell them, that's the fundamental building block of becoming a scientist. And I tell them, give me a chance to draw that out of you, find that curiosity, find that sense of wonder, and you will be a science person before you know it.

And, of course, as I'm teaching this course, I give them a sense of what is to come. Sure, I cover Newton's law. Sure, I cover classic mechanics. I even cover some E and M. I don't tell them what Maxwell's equations actually look like, but we dive into those topics a bit, right?

The bottom line is this: I try to spark that curiosity by saying, look, yes, we will cover the classics because that's what you need to cover. But I'm not going to stop there. I'm going to give you a little taste of Einstein. I'm going to give you a little taste of quantum mechanics. See, that's where the cool sci-fi physics lies. Entanglement. I call it teleportation to my students. That really gets their attention. Even if it's quantum teleportation, it's still fun.

You can get into the idea of, well, how do we get out there and explore those stars, right? Maybe talk a little bit about relativity. See, that could be the gateway out there. And people ask, why should I care? I'm not a science person. You know what I show them next? A video of what's going to happen to the sun when it becomes red giant. I say we better care. A couple billion years, we got to figure out some stuff. Right? That convinces them pretty quick once they see what's going to happen.

Bottom line is everybody should care about this stuff. Not that I'm biased or anything. But I think we should. So I try to grab their fascination by throwing in those other topics, as well, and it tends to work pretty well. And then they transition from I am not a science person to wow this stuff is pretty cool. This is stuff I want to teach. Right? Because let's face it, what's better to teach than science? I mean, come on. Not that I'm biased, but I am. There's nothing better than teaching science.

Okay that's one way to bring them along. You show them that spark. You show them that joy. I always say, if you're the teacher, you set the tone of the class. If you're having a miserable time, I'm teaching science, then your students will have a miserable time, I'm learning science. But if you walk in going, yeah, I get to teach some science, everybody else will go, yeah, I get to learn some science.

It's amazing how often the students feed off the teacher in there. And that's what I tell my education majors. I say if you hate science, your students will, too. And you know what happens? That makes my job a lot harder by the time they hit my classroom. They walk in going I hate science. And then I say all right, I have to have that conversation again. Right? So there we go.

So what do I tell my students then? Yes, you will struggle. Right? In general, most people tend to struggle with science course. When people say I am not a science person, they say I don't have a talent for this. And I say did you know that so many famous people have said it's not talent that counts? It's persistence. Not giving up.

In fact, one of the things I read years ago was an interview somebody did with Isaac Newton. And they asked him, they said, so how did you come up with this fabulous stuff? And he gave a very similar answer to what Einstein said when he was asked a very similar question. I find that fascinating. They both gave very similar answers.

And they both said something along the lines of, I don't remember the exact quote, but I'll give you the notion of it. It was along the lines of whenever I came across a question I could not answer, I did not give up until I could answer it. I thought that was interesting. When most people would say it's too hard, forget it, I kept pushing and I was not satisfied with, oh, I don't know. It's too hard. I kept pushing until I could figure it out. And they said that was the key difference on how they made these great discoveries. And I find it fascinating they gave similar answers in that sense.

You see the quote here from Calvin Coolidge right along those same lines. So when somebody says I'm not a science person, I say you've got what it takes. You've got the curiosity. As long as you've got the persistence, you've got everything you need. Right? You will get across the finish line as long as you don't lose focus, as long as you don't give up. Right?

What else can you do? Shifting this personal identity. This is actually a fairly recent paper I came across a little while back where they were looking at how to encourage students and will that shift the way they view themselves? And the answer is if you do it in the right way, it can.

So one of the -- well, two of the big results they found is they looked at two different types of recognition here. Explicit, implicit. Explicit, telling them you did a great job. You're actually doing good work here. But you can't say that on easy busy work, because everybody sees through that. Well, okay, I solved one plus one. It's two. "Good job!"

That doesn't do anything for me. But give me something with a little more meat on the bone that's a little tougher to figure out and I accomplish it? That does feel pretty good. That's building me up.

Implicit, explicit. Implicit, it's not just busy work. Give them a real challenge. But explicit, when they cross that finish line, let them know that you know that. That means a lot to your students. Right? And this does shift their personal perceptions of themselves. This has been shown to work here. You've got to do it in combination, though. You really do.

All right. Now we get to the thorniest one of all. Personal beliefs. The ideas about evolution, climate change, the beginning of the universe, right? These are some pretty powerful ideas that people have very powerful thoughts about and there have been many times where I've been teaching class and a student walks in and tells me, Dr. Richards, I've been taught all my life that scientists are out to get me. They are out to disparage my ideas and tear them down, and I've been told to fear scientists for that reason. And I'm, like, oh, my gosh. Okay. I've got to change things on here.

So how do you address this? When someone walks in with that wall up instantly that, you know, if you're going to reach them you've got to get through that wall somehow? Right? Here's what you do do: Run right out and say you're wrong. That's not going to work. Because then the wall gets bigger and stronger. How do you get through that wall? See, that's the real question.

One of the things that I've done, and sure enough, you see this in the literature again. You don't run right at them and say you're wrong, that's it. You've got to think about it this way. Instead focus on what you can observe. Focus on allowing them to see the phenomenon on what's happening. Again, they're generating their own ideas here and not mine. They own the ideas if they generate them. It's not me.

I'm here to put them in a situation, a scenario where they then see the ideas I want them to see without me telling them. Because again, if it's not me telling them the ideas, I'm not trying to punch through that wall. They're climbing over their own wall when they see it for themselves. Which I think is kind of interesting, right?

And in fact, funny thing is, I've seen this in many students in my own classes. They'll tell me this in the first week of class. My students are very up front with me. I kind of like that, though. They'll tell me, yes, I've been told my whole life scientists are this big, scary thing. And by the end of the semester, they're like, you know, you're not exactly like what I've been told about scientists. You're kind of different. And I went, well, believe it or not, I'm not the only one who's like this. We're all a pretty good group.

Well, what changed about this? I didn't run right at them. I didn't just say, you're wrong. I allowed them to discover a lot of the stuff on their own. And they walked away going, wow, that actually kind of made sense.

Notice what you do when you put them in that situation. See, if you run right at a person, you activate a very basic notion that's built into the human brain. In fact, it's part of our survival instincts, fight or flight.

See, if you attack a person, the very primitive part of the brain kicks in and as a survival instinct, the brain will immediately shut down all higher levels of thinking because it thinks I'm in mortal danger and I better concentrate everything I've got, all resources, all hands on deck need to focus on one of two things, either run away or fight back. I'm not going to do anything else right now because I am in mortal danger and I'm going to be attacked.

That's the last thing you want to activate with a student. Right? You don't want to do that. Because the moment they get into fight or flight, all the higher level stuff shuts down. And all they're thinking is, what am I going to do here? Do I bolt or do I fight? You're not going to win any arguments by going up against somebody in that mindset. So you don't activate that. Right?

That's why you don't run right at them. You let them climb over the wall themselves so that way their higher level thought processes are still rolling. And that's what I want in my classes, I want those higher level thought processes rolling as much as possible. So I don't activate these survival instincts.

In fact, physics should not just be about survival instincts. My goodness, what's the fun in that? Should be about other stuff. The higher level is what I want to see. Not the basic, oh, I've got to survive this kind of thing. Right? No, physics is a lot more fun than that. Okay? Those are just a few strategies. These are the trickiest ones, I will tell you, to dig out.

All right. That's all I have for tonight. Thank you very much.

(Applause.)

Any questions?

>>STUDENT: How would you apply this to change your habits, change your own habits? Because the way you're talking about affecting and influencing people, what if you want to use that on yourself?

>>DR. RICHARDS: That's a good question. Hmm. So one of the things that I suppose would facilitate, say you want to make a change, would be first off keep that open mind. Right? Be open to a different way of thinking, a different way to approach things.

You know, one of the things I heard years ago, which kind of stuck with me for some reason is someone had said, you know, if someone walks in with a certain mindset and it's deeply engrained, that means it's probably been a productive mindset for them in the past. But maybe it doesn't work so well right now in this state. And it's awfully hard, though, to dig somebody out of a mindset that has been productive in the past that may not work so well anymore.

And the way you get around that is so you keep that open mind. You have a genuine curiosity. Maybe I need to explore this alternate way of thinking and not get so locked into, well it's got to be this way because it's always been that way for the last thousand years, at least in my experience. Maybe there's another way to go about things.

And so being malleable a bit, right? Being open to new experiences. Being open to new ways of looking at things. And, you know, being a scientist, there's a lot of that built in. Right? So in many ways, having an interest in science kind of primes you for that.

Because, when, say you present some work and you feel great about it. You feel like you've studied every single angle of it only to have somebody throw a monkey wrench in your plans by asking the question you hadn't thought of yet. Right? Part of the joy of being a grad student. And all the grad students are like, yes, I know. Present at research conferences and then you get that one question like, hmm, didn't think about that.

That's actually a good thing, right, because it gives you a chance to go back and fix that up so no one can nudge you on that one again, right? So there's real value there. Good.

>>STUDENT: How would you integrate this into lower levels of education to start getting kids thinking like this early on and making it easier to transition into high school and even into college (inaudible)?

>>DR. RICHARDS: Oh, really good question. I would say first off, more of the team-based learning is crucial. And the good news is that's beginning to take hold. In fact, over the last just ten years I've been at Lee, I'm now seeing more of that appearing in our local ISD. I kind of like to think, although I'm sure it's not true but I'll take credit for it anyway, that some of my students are now out there beginning to integrate some of this in. I know it's not true. It's a vanity I take.

But you are beginning to see this erupt at more and more places, and it is working its way up the chain. Honestly, these ideas, this notion of working in teams, team-based learning, started actually at a community college. It's called workshop physics. So it started with folks named Priscilla Laws, and she started working on this, and she's like wow, this stuff works pretty well.

Then folks like Bob Vigner at NC State, that's where I did my Ph.D., caught wind of it and goes, could we actually do this not in classes that are small like you get at community college, but really big ones, like we get at universities? And he started playing around with those ideas and he figured out how to do it.

Although random anecdote, I can't resist. I love telling random stories. So the first time Bob ever tried to do a studio style classroom was not in a studio classroom. When I say studio, I mean a bunch of table sitting out. Everybody is working in teams at tables. First time he ever tried it was in a lecture hall a lot like this because he was thinking, well, if I'm going to adapt this to the big universities, this approach of everybody working in teams at work stations, most universities already have big lecture halls. Let's see if we can make it work in there.

And, oh, by the way, I'm supposed to go on sabbatical this year, so I'm going to hand this off that first semester to my friend over here, John Rizzoli. John told me it was the worst semester he ever taught in his entire life. He goes thanks, Bob. You just handed it off to me, and it was terrible. Because it doesn't work well in a giant lecture hall like this. You need that active learning layout like we have down the hall. It just doesn't work in a big lecture hall like that. So the early days kind of showed that.

So in terms of addressing it, as early as possible, get people working in teams. Lots of guided inquiry so students are used to that mode of learning. A lot of students, when they first come to me -- I get a mixture now. Early days it was a lot of everyone walks in going I expect you to lecture to me and tell them everything and then I will spit it back out to you on the test exactly the way you said it and then I totally forget about it the moment I leave the classroom. That's the way it's supposed to be, right?

So some of them do get this kind of culture shock when they walk in the classroom. Oh, my gosh, he's not telling us the answers. No, I'm not. I'm asking you to figure out these things. So the less of culture shock that's early on that can address that, that would certainly be helpful, as well.

>>STUDENT: Does a traditional lecture have a place in your (inaudible)?

>>DR. RICHARDS: So there are reforms out there that have been specifically designed for a lecture hall a lot like this. And so the answer is yes. You can do things that can add some punch to a lecture hall.

Give you an example. So earlier today I was going to ask you multiple choice questions. Asking everyone to vote. Well, of course, there are electric response systems out there, clickers as they're commonly known as. But research has shown it isn't good enough just to ask clicker questions. You actually have to have an interactive engagement element to it.

So, for example, when we were fiddling over here on the computers, notice what I asked everybody to do. Turn to your neighbor. Battle it out with them. See what they think. That's called peer instruction. So if people struggle with a certain idea, and let's say you get the responses and half the class thinks it's this answer and the other half of the class thinks it's that answer. Maybe this half is right and the other not so much?

I love it when that happens. Because then I can say turn to your neighbors, battle it out in your teams. Convince them you're right. And you know what happens? Nine times out of ten, we converge on the right answer after we've done that.

>>DR. GARRISON: I was going to point out if anybody is taking a class in the bayou building (inaudible) over there, there's one on the second floor near (inaudible) office, for example, you'll notice that this lecture hall is a lot different than that one in that all these chairs you're sitting in, they're not locked into the desk. And you know, so there's a white board behind the rows.

>>DR. RICHARDS: That is slick. I like that.

>>DR. GARRISON: That's not by accident. This is actually meant so that some of these interactive learning tools can still be used here, even though it's not a completely interactive room. So that's why these are not -- you know we could have gotten chairs that were bolted to the desks (inaudible).

>>DR. RICHARDS: That's a nice idea, I like it.

>>DR. GARRISON: And you see little whiteboards in the back and (inaudible).

>>DR. RICHARDS: That's nice. I like that.

Now, one of the challenges that I've found this semester in particular is this semester I'm only teaching the lecture part, I couldn't squeeze it in my schedule to do both. Sadly enough. I love doing both. But that's okay.

And one of the things I have discovered is, see, I haven't taught in that mode in -- wow, 15 years? Has it really been that long? I've taught integrated lecture lab for a million years now it seems like. But the bottom line it -- it has been a long time -- is one of the things I have noticed is that the smaller time frame that you have to work with when you're just doing lecture as opposed to lecture lab where you get the big, beautiful three-hourlong blocks, with only an hour 20 I do have to adapt a lot of my approach.

There are certain things I would normally do as a big activity, it takes two hours to do. I can't do that in an hour 20, right? So there are certain adaptations I have to make, as well. So it's been a really interesting experience, you know, teaching just the lecture part. I still try to do some active learning and we still do some activities but I can't do them in the same way that I would run an integrated lecture lab course. Like I said, it's been an interesting semester for me on that.

>>STUDENT: Would you advocate (inaudible) dimensional concepts in physics?

>>DR. RICHARDS: Yes, absolutely. In fact, there is software out there now that started with V python, visual python, that was specifically built with physics in mind. In fact, the folks who started it were physicists. Well actually one was computer science, the other was a physicist and they were working together.

And the idea is you program something in python but you are given access to a library of custom commands that you can easily create 3D images of objects. Well, it 2D but 3D representations of objects. Like you can say sphere and specify the radius of the sphere, where the middle of the sphere is to be located. It's on a 3D axis, x, y, and z coordinates. And when you run it, it'll automatically generate sphere. You can zoom in and out, you can rotate around in all three axes that you like and look at it from different viewpoints.

And so what V python has done is they've given you access to this library of commands that make it dead easy to build very complicated landscapes that are out there that you can then build in the physics for how it should move.

>>STUDENT: (inaudible) equations, and the equations themselves become physical entities.

>>DR. RICHARDS: And probably the closest approximation would be something like VPython. Although they graduated to GlowScript now. Best part about GlowScript, you install nothing. You run it purely through the browser.

And what I really love about it is the computer does not know physics. You have to give it the equations for it to then understand, how do I make this ball move? Like, drop a ball let it bounce. You have to feed it the equations of motion. You have to feed it, how do I handle it when the ball hits the ground? What analysis do I run? You have to give it all of that because the computer knows nothing about that. All the computer knows is I will draw what you tell me to draw and I will change its position based on the equations that you give me.

So the best part about that is you lift off the shoulders of the students this need to learn rather advanced programming libraries to draw this stuff themselves. The computer does that. And instead they get to focus on developing the equations of motion directly in the code itself.

And so it strips away a lot of the computer science elements, not that those are bad. Don't get me wrong. But when you're teaching intro physics course, you really want your students to drill into the physics as opposed to computer science side.

And that's where I think the power of GlowScript really lies is the computer is completely dependent on you, the programmer, to feed it the physics. You have to give it all of the physics for it to work.

>>STUDENT: (inaudible).

>>DR. RICHARDS: Oh, it's GlowScript. Let em go ahead and pop that up here on the screen. It started at VPython but nowadays the developers of VPython have moved on and they've developed GlowScript -- script.org. Go to that website. And you can program directly in the web browser. No need to install anything. That was a major leap forward. VPython you had to install stuff. But this, there's no need to install anything. You just run it right in your browser it works great. By the way, you will have find whole sets of physics labs for the intro courses that people have developed specifically with GlowScript in mind.

>>STUDENT: (inaudible)?

>>DR. RICHARDS: Yes, so there are tutorials out there, help files, all kind of great stuff. And feel free to reach out to me if you have any questions about it. I do try to integrate some of that into my courses as well.

Question?

>>STUDENT: How, I guess, is a way to (inaudible) quite a bit, but so it was really cool coming from Lee College, but transitioning over not realizing what you guys were doing (inaudible) the basics of my higher education to coming here to a course where that's not completely integrated in. So it was a big difference and it still is kind of different for me to try and figure out, okay, well, this is just lecture and like you were talking about, it's harder for that stick for me now that I have that basis.

So do you have a way that those students that are going to go off to a school that isn't integrated that way, if that makes sense.

>>DR. RICHARDS: It's a good question. One of the things is -- so this might give you some heart -- is they have done longitudinal research. It is limited. They haven't done a lot of it, but what little they've done, they've traced students. How did they perform after they left the integrated courses? They do better, believe it or not.

One of the things we looked at was university physics one that leads directly into statics. And they traced how do the students do in statics that came out of the integrated format? And sure enough, they did better across the board. There was better retention. Of course attendance was way up, and the scores were higher, both the standardized testing scores as well as the scores they got in the course itself.

So there hasn't been a lot of longitudinal work, but what little there has been, it's very encouraging. So it does have a lasting impact. So that's the good news.

>>STUDENT: I was going to ask you, how would you suggest using these techniques in working one on one with a student who doesn't go to a school where these ideas are integrated. So for example, like I tutor elementary through middle school primarily and a lot of them are not getting this kind of education. So how can I one on one kind of use these techniques to help them start training their brains to start thinking this way so it is easier for them in school and up until they get --

>>DR. RICHARDS: Very good question. So one of the things that you really cross over the border from the science of teaching into the art of teaching is something called the zone of proximal development. So let's talk about what that is first. It's a result out of psychology research. (inaudible) came up with it.

And the idea it this: There are certain leaps in logic that an individual can take on their own. And there are certain leaps that they simply can't do on their own. And so this border between what I can do and what I can't do, that border between what I can do and what I can't do, that border is called the zone of proximal development.

So if you can push a student to get as close to that edge, that border as possible, that will be that will have the most meaningful, most powerful impact on them. And that's the basis behind guided inquiry in that a well-designed guided inquiry activity will get you to that edge but not past it. Because if you go past it, this is frustrating. I can't do it. I give up. But if you jump too shallow, that's too easy. That's pointless. That's busy work. I don't care.

The closer you can get to that edge, the more powerful it will be for them. So when you're working with those students, consider, okay I see you struggling. This is more the art of teaching. I wish I could give you more the scientific process. But you have to kind of calibrate yourself to how far can I push this student?

And instead of just saying the answer is five, focus instead on giving them a nudge in the right direction, pushing them to that zone, so they are taking the leaps to get there themselves. You're just giving a little nudge as they go.

There's an old saying out there in education research, being a guide by your side instead of a sage on the stage. Right? There you go. That's kind of the focus here. And those are some of more powerful techniques to tend to show up in the research.

>>STUDENT: (inaudible) Socratic questioning (inaudible)?

>>DR. RICHARDS: Socratic dialoguing.

>>STUDENT: So if you ask the right series of questions and not necessarily yes or no questions (inaudible).

>>DR. RICHARDS: Right.

>>STUDENT: So sort of along those lines of what she was asking, when you're looking at adolescents (inaudible) to early developing years, part of the issue at the later stage is (inaudible) (laughter) so, you know, like music. Start them off young, give them (inaudible) as they grow, right?

So when you're talking to somebody who doesn't have the experiences that have been gained over a longer lifespan where you would normally be trying to input some analogy to try and make it make sense, when you're talking to someone of that age, to what level -- and you were just talking about (inaudible) kids get, but to what edge should you really push it? Because if you go too far, then it becomes uncomprehendable to them.

But (inaudible) but at that level, I mean, how deep should you go with a child, just to get them to understand what's right? What's wrong? As well as to not use them (inaudible)?

>>DR. RICHARDS: Right. So part of this -- again we are bordering onto the art of teaching as opposed to the science. There is that calibration that you kind of have to go through. And I know early on in my career, I did struggle with that a bit and I would try to push it way out here and we weren't ready for that. But as time went on, I got better at gauging.

And the way I kind of approach it is I kind of kick things off with asking some probing questions. You know, what do you think about this or that? Just to kind of get a sense of where are we at right now. What are your beliefs about what's happening right now?

And I also, when someone comes to me for the first time and I'm not quite locked in on them, I do allow them to talk quite a bit at first. I'll say, well, walk me through what you did here. I don't understand this. Really I'm drawing out, what are your thought processes at this moment?

>>STUDENT: What age are you talking about here?

>>DR. RICHARDS: So I have done this with -- well, okay, granted that was a prodigy but years ago I taught a 9-year-old prodigy that I did this with. Wow, that was an exceptional student.

But I also do this on a regular basis with high school students. We do have an early college high school within the ISD that Lee College serves. And so I will teach a fair amount of high school students, as well, in my courses. So for me personally on a regular basis, I've done this with high school age students.

Now, with that being said, I also do a fair amount of outreach where I go out to elementary schools and middle schools and I will work with those students but very temporarily. So I can't tell you I have a great deal of experience working with exceptionally young students on a regular basis. It's more of I will work with you a little bit just to kind of show you some things and draw out some cool ideas. But for those exceptionally younger students, I don't have a lot of experience there. My area is more of high school and up, you know?

And the funny things is in my class especially, I see this at the community college quite a bit, in one class I will have three or four generations of students. And I will have to to find ways of reaching someone who is, I'm now retired and I'm taking a class for fun, to I'm in high school taking this as dual enrollment course. And I'll have them in the same class. It's a fascinating experience.

>>STUDENT: (inaudible) so do you think it would be too much to -- like when I was in math, in my undergrad math classes, the instructor would go over something. And then -- but it -- from that point, it branched out to something more complicated. And she would stop there because it's outside the scope of the class.

But that still kind of leaves you wondering, well I have this here and I don't know how to make sense of it. But even if I don't understand what you're about to say next as to where this goes, that's still -- it doesn't leave me in the lurch, right? If you've ever heard that.

>>DR. RICHARDS: Right. Yeah.

>>STUDENT: I at least know from this something happened with it. I may not know what happened with it or at least understand it, even though you're explaining it to me as best as you're able to to, a Ph.D. or whatever, right? Still, I can see where it's going. So (inaudible) but, you know, for a child do you think that's too much to just go off -- not like totally off, you know, and start talking quantum and stuff. But enough to where they see I'm telling you something and I'm giving you the simple part of it, but there's more to the story and as you grow and as you live you'll see how that story -- just so they have an idea that it stops here and then (inaudible) the rest of it as (inaudible) at least there's a path laid out for them.

>>DR. RICHARDS: You know, one thing I do is if I'm working with particularly younger students who are not quite ready for the heavier lifting, what I will do is describe the big picture, some of the cooler avenues, but in very general terms. In other words I try to use plain old everyday ordinary language. I don't dress it up with the technical terminology if I can get away with using very simple, basic terminology.

And to give you an example, you know, when you're talking about something as basic as why is the sky blue? Yes, you could explain this in a very deep and technical way, get into Rayleigh scattering and all that. But you don't have to explain it at that level if you're dealing with, say, a much younger student. Right?

One of the things I teach in that physical science class is we answer that question but we don't get into the mathematics behind it. Instead we talk about the ideas, the concepts. You know, this notion that you have the sunlight coming in. It's interacting with things up in the atmosphere.

>>STUDENT: (Inaudible).

>>DR. RICHARDS: Yes and you get this --

>>STUDENT: (Inaudible).

>>DR. RICHARDS: Exactly. Exactly.

>>STUDENT: (Inaudible).

>>DR. RICHARDS: Right. So, you know, you could talk about how, okay, so it interacts and what it's result? Like you said you get some of this bending and you predominantly get blue coming down and not so much red. And what's a sunset? It's leftovers. But I don't phrase it in terms of -- I talk in terms of, it's the leftover light. You get the blue. What's the other side of the rainbow? It's the reds and what not.

>>STUDENT: (inaudible).

>>DR. RICHARDS: Well -- so, right. Well, okay. So, you know, you've got the light coming in. You've got Rayleigh scattering going on. So you get the predominantly blue coming out, right? So then you look at it more at dawn, at sunset or sunrise. And you can see this in the scattering tank. You can see how the light transitions. So take a big tank of water, pour some Pine Sol in it, the more the better. Stir it up. So you get the little bubbles in there. Shine light through it. You can see this effect for yourself.

So I do it more as a demo, as well. And funny enough, the way we discovered Pine Sol works well, we don't we did something we're not supposed to do. Don't tell anybody this. I know I'm on tape. We got the scattering tank and they had this solution of something, they didn't tell you what it was. And they said pour it in and agitate it. Right? So we did that. And then we kind of, like, we recognize that smell. Right? And we went, yeah, that's Pine Sol. You're not supposed to do it. But we did it anyway. And sure enough, it works great.

So getting up a very simple demo where they can kind of see it for themselves. But again, not getting into the mathematics of it. You don't have to do that if you're talking to a very young student.

>>STUDENT: (Inaudible).

>>DR. RICHARDS: Yeah, exactly. And for me early in my career, one of the things I really had to learn is -- so when I was coming out of my Ph.D. program, one of the things that I had a lot of experience in teaching was university physics.

Now, the thing about teaching university physics is you now have at your fingertips a whole host of mathematical tools you can use to talk about this stuff. You can use derivatives. You can use integration. All that's fair game.

But one of the things I started teaching early on at Lee was also the conceptual physics courses. You tell a derivative to conceptual student, they will run out of the room screaming. You can't use that. You have to go to other ways of representing this stuff. Right?

So those early experiences shaped in many ways what works and what doesn't. So there is a certain degree of experimentation here in trying to understand. If I explain it in this way, it's a disaster. But if I explain it like this, they tend to key off that more. I wish I could tell you there's a paper out there that says to do it exactly this way. There isn't.

It is more of an experiential thing, kind of seeing what works for you. In that sense, each instructor out there has their own unique strengths and weaknesses. To give you an example, one of my research advisers at NC State tried teaching in the studio learning environment, the one where Bob Vigner, the guy who originated it himself at the university level, he taught it there and so he roped everybody else in and said you've got to try this. We got incredible results. And he did. He got outstanding results in that room.

My adviser tried it and she goes, I hated it and students hated it, too. It doesn't fit with my teaching style. And if it doesn't mesh with your own particular style, it's going to be a terrible experience for everybody.

So in that sense it's one thing to be very cognizant of the reforms that are out there. But at the same time, one of the things you have to be aware of is how do you play to your strengths and implementing them? And maybe what works really well for me may not be the best thing for your own personal style, as well.

So, I think the big lessons are, take the broad ideas out, but then you may have to adapt them a bit to make them work for you. Right? And so this notion of having the students come across the ideas on their own, that's a very powerful one. But the way you do that may vary depending on what works for you personally versus what works for me.

>>STUDENT: (Inaudible).

>>DR. RICHARDS: There may be something else out there that's a better way to do it. As a scientist, I have to acknowledge that. I can't tell you this is the best absolute way to do it. There maybe another layer to that onion to peel back, something we haven't discovered yes. And that's part of the fun.

>>STUDENT: I know from firsthand experience that it can be frustrating that guided inquiry works for smaller class sizes like university (inaudible). What happens when you scale it up? Let's say (inaudible) full room (inaudible) 30 or more students?

>>DR. RICHARDS: It works. In fact, at NC state we had a room that fit 99 students. Eleven table, nine at each. And I'll never forget this. It was in my second semester of

teaching in that particular room and I was there as a grad student. So I was -- you had a room where you had two grad TAs and you had one lead professor and they were over 99 students in there. So the ratio wasn't crazy. You're still about 30ish to one. So it's not a crazy ratio.

Well, as it turns out that particular semester, the -- there were some budget issues and they had to cut back on how many TAs they had in the room. So it was just me and the lead professor. So now all of a sudden the ratio is getting a little more hairy. But I'd already had a lot of experience being a TA in there. I kind of knew how the room functioned, I knew what we were doing, and I worked really well with the professor. We got to a point where we were pretty much on the same wavelength.

Okay, so we made it work. Well, the professor then comes to me and says I've got to be out for the next two weeks at this conference in Italy. Good luck. I went, okay. Here I was, me and 99 students in there -- actually, it wasn't a full section. It was about 80 students. Me and about 80 some students in that room. I ran it for two weeks. That was fun. That was an experience. I was literally sprinting from table to table trying to touch base because that's part of the secret sauce of that room, you are all the circulating around trying to touch base with as many tables as you can before times runs out. Okay, we've done this activity, we need to move on to the next one.

And so I had never worked so hard in my life to keep things rolling for those two weeks. Needless to say, I was pretty grateful when he came back. I was pretty much exhausted by the end of that. You can make it work. I made it work.

And funny enough, it was after that semester that the department came to me and said, would you like to be lead instructor on one of these yourself? And I said yes. Sure, I will take that. And they at least gave me one TA to work with.

But in any case, yes, you can do it on big scales. It has been shown. And there are some adaptations you have to do. In other words, workshop physics, it's not exactly the same as the scaleup implementation, which is the big university implementation. But there's a lot of crossover there, too. Right?

>>STUDENT: Are there any outreach programs for those that are interested? Because you mentioned outreach earlier, that you did outreach. Are there any programs you know of that are open to students that want to teach younger students (inaudible) and if there aren't, have you thought about developing (inaudible)?

>>DR. RICHARDS: Oh, boy. Got me on the hot seat here, huh? I love the idea, actually. Because the more people I can integrate into these active learning methods, the better. Short answer is, the outreach programs I've developed, we have mainly built to serve the ISDs in the Lee College area.

And it's not to teach them how to teach, it's more a focus of I'm going to show you some cool science. Hopefully you'll walk away with a broader horizon and interest that's been sparked to I want to learn more about this.

So coming up in March we're going to have what we call STEM day. We invite a lot of high school students out, run 30 minute sessions in all fields of STEM. I'm running one of the physics sections. I get to teach them the secret to all music, which is a lot of fun. So we get into harmonics and things like that.

So we'll do things like that year round. Those are great, but it's not teaching them how to teach. It's just trying to spark some inspiration, some fascination of that's something I want to learn more of.

>>STUDENT: (Inaudible).

>>DR. RICHARDS: I haven't been over here. Let's see. I've answered one for you. How about over here? I haven't answered one for you.

>>STUDENT: So the Physics Education Research helps you figure out (inaudible) how to handle (inaudible) solve those issues, and you can also apply that with different learning styles, active learning (inaudible). What happens when you have (inaudible) or people with learning disabilities and how does that fit in (inaudible)?

>>DR. RICHARDS: Oh, great question. So the short answer is, is it's kind of embarrassing to say there hasn't been as much research on that as frankly there should be. So the research is leaner on those topics.

You know, and me personally, I have had a few students who have had challenges. And the reality is, you know, I am very fortunate in that at Lee we have just incredible people at Lee who are really good at helpings me work with students who have challenges. And so it becomes a team effort at that point, you know.

You're working with your support services. You're kind of bringing in your own strengths and weaknesses to the equation. And as everybody -- the student, support services, and me -- working together, you kind of figure out a way to provide a path forward for them. But in terms of specific research targeting that, yes, it's sad to say there's not as much as there should be out there. Yeah, very good.

All right. Thank you.

>>DR. GARRISON: All right. Let's thank our speaker.

(Applause.)

>>DR. GARRISON: First off, I want to let everybody know next week we have David Alexander is going to be here from Rice University giving a talk on space weather --

(No audio).

(End of class)