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[MUSIC PLAYING]

KIMBERLYN LEARY: So happy Tuesday, everybody. I think it's Tuesday. How many here are faculty? Great. Staff? Students? Excellent. Anybody I miss? Another category of folks?

Excellent. It's really terrific to have this kind of a platform for there to be engagement across faculty, staff, students because we're all in it together. And that's what this program is really about, trying to help us to appreciate what it really means to disrupt some of the traditional hierarchies that are in the classroom and how to create the kind of learning platforms that will enable all voices to count, and for all of us to be in the mode of learning.

So classrooms, as we know, have traditionally really been built on these hierarchies. And in fact, sometimes professors have actually-- and universities have actually tried to enhance them. But we're here to deconstruct them.

So those hierarchies typically mean that the instructors hold more knowledge than the students, and power. That's also important. That right answers tend to count more than so-called wrong answers. And that those with more experience in and knowledge of a subject are considered to be smarter than those who bring less experience or different forms of knowledge.

So we're going to try to challenge some of those hierarchies going forward and look at what it's like to create a classroom where the wrong answer becomes exactly the pivot to more learning and deeper learning. This is really powerful. It's also very difficult to do.

So I've had the pleasure of teaching at several of the Harvard schools. And at the Kennedy School, for example, in classes where we try to use the classroom as a case, as a case in point, rather than just reading about a case, for there to be a case-- that is us.

When we try to turn the authority over to the students, what we learn very quickly is that they keep looking at us, the professors, for cues. They keep trying to hand the authority right back. And we try to give it to them, right back. So you can see that it's easy to say that we want to disrupt those boundaries, but much harder to put into practice.

At the School of Public Health where I teach doctoral students, a different kind of challenge there where you have a lesson planned on one topic, but comments come that, from a very different perspective or a different problem altogether. And you have to figure out how to be flexible, how to balance that flexibility and student agency with exploring the given course content that you're actually been asked to teach and to share.

And then, when I've been teaching freshman seminars, which I have to say is a complete delight, the experience of watching Harvard freshmen who worry a ton about how they'll be perceived by faculty and one another. To watch over the course of the semester as they grow more comfortable learning from one another, it's just such an incredible privilege.

So I'm excited to have this chance today to see how Professor Johnson approaches these dilemmas, how he disrupts traditional classroom hierarchies. And then we all will have a chance in the spirit of this to reflect together on what we've seen. So with that, let me turn it over to Professor Johnson.

JOHN ASHER JOHNSON: Thank you.

[APPLAUSE]

I had a sheet of paper up here. Did that go with somebody?
KIMBERLYN LEARY: Well, yes, I took your sheet.
JOHN ASHER JOHNSON: Thank you.
[LAUGHTER]
KIMBERLYN LEARY: I'll give it back.
JOHN ASHER JOHNSON: I have notes.
SPEAKER 1: Didn't want to disrupt.
JOHN ASHER JOHNSON: Yes.
[LAUGHTER]
So we are going to be doing a simulation. And so I welcome all of you to astronomy 16.
[LAUGHTER]
This is a class that is going to focus on our understanding as human beings of the objects and phenomena that take place within our own galaxy. And so many of you already have approached me before this semester started, asking me if you could join this class without the necessary prerequisites in both mechanics or in calculus.
And I assured each one of you that it is OK for you to be here, provided a couple of things-- first, is that you might have some catching up to do. But I first want you to understand that catching up is not the same as being less smart. So if you are willing to enthusiastically put in a few extra hours at the beginning of the semester-- my teaching staff is available to help within the Learning Center, the Astronomy Learning Center that we offer twice a week. And I'm also available for personal office hours to help you review as necessary and sometimes to learn some of the base material that we're going to need for this class.
But one of the things that I really enjoy about this class is that even though we're talking about very sometimes esoteric and abstract phenomenon, we can actually draw upon our own physical intuition-- not just the intuition that we learn from a physics classroom, but the intuition that we have by being human beings on this planet. And so today's activity is going to leverage that intuition that we all bring into this classroom.
By a show of hands, is anybody in here already earned an astronomy degree? OK. That's about what I expected. Nobody in here is an expert in astrophysics except for myself and the teaching staff. And all that means is that we've been doing this years longer than you. But I believe that by virtue of showing up into this classroom, you have the skills necessary to learn this material.
So let's go ahead and talk a little bit about the structure of this course. First of all, we've already covered the syllabus, I think.
[LAUGHTER]
And as you saw, I don't put a lot of weight on the exact structure that's in that syllabus. I hope the syllabus just gave you a taste for what we're going to be doing this semester. But it will not be a map that we're going to hit waypoints along the way.
Doing that would make the assumption that everybody in this room learns uniformly at a uniform pace, and that that pace can be set before the semester begins. I don't believe that this is possible.
I think every single semester, I have a different composition of students. Everybody brings a different set of experiences and skills to the table. And then we progress at different speeds. And so that speed that is

set each semester is something I call the speed of learning. And so that's an important concept-- probably far more important than any astrophysical concept.
And this is sort of an average pace that we need to go in order for everybody in this room to learn the material deeply. And by learn the material deeply, I mean that after we're done-- well, before we start, you might not know how to explain anything that I present to you on one of these worksheets, for example. But by the time we're finished, you should be able to explain it to, let's say, a family member, a friend. You can break it down at a level that they can understand it as well.
And I think that's a good measure of actual learning. And to get there, we cannot set that pace ahead of time. So that means that we're going to need to be flexible in here. The teaching staff and you are going to need to be able to take our time.
That's going to be new for all of you Harvard students-- taking your time. Not demonstrating how fast you can do it, but demonstrating that you can slow down instead and dwell a little bit and ask questions and be a little bit stubborn about not moving on until you feel like you've learned. Once the class has gotten to that point, I think we're going to be ready for the next topic. But I'm not going to be driving us towards that next topic.
One of the things that's going to facilitate that is the structure of this course. What we're going to be doing is-- there will be some lectures. I'll be doing some lecturing. That will be necessary to set the stage for each new topic. And sometimes at the end-- and I'm doing this more and more at the insistence of my students-- is to review after we've covered a topic. That's something I'm learning from my students.
But outside of those brief lectures, we're going to be spending the majority of the time in groups working collaboratively to solve these problems. This is not a place for you to come in and demonstrate straight individually how smart you are to other people. There are plenty of other classes on campus for that.
If you are here to show how smart you are, to demonstrate how much skill you have in the areas of math and physics, this will be a disappointing semester because that's not the point of this class. Now, we all know how that looks when there is a drive to identify who the smartest person in the room is. That's a way that a lot of science environments are set up. But I don't believe that that's where most of the good science takes place.
Most science progresses through collaboration, which means that we are in a community setting bringing everybody up to speed, bringing everybody up to a sort of common mode of knowing. And so really, what science is about in my experience is spending a lot of time being wrong and being stuck as a result of being wrong.
And the best way to get unstuck is to work with other people who bring other skills, additional knowledge that you might not have. And you can work together in community to solve that problem. That's how science progresses, and that's the structure of this course.
The last thing I want to emphasize is that there will be a temptation to ask about grading as we go along. What is your grade? What grade did you get? I want to encourage you to not do that. That is my least-favorite question to ask-- I'm sorry, to have asked and to answer over the course of the semester because that is a question that is distinct from the question of, have you learned?
Demonstration of learning sometimes correlates with the grade that you get. But if you are driven by the grade, it will often distract you from learning. And so we want to emphasize process over product as we go through the semester. That's going to be a theme. I might not repeat those exact words, but it will be embedded in the approach that my teaching staff and I take to helping you and facilitating your work on

the problems, is that what's more important than the final number with a box around it is the way that you got there.
Did you get there in a way that is reproducible? It's reproducible because it's legible and understandable by others. And so as you work at the board, please take care to be able to answer the questions that we will ask you inevitably about your work. And here's a fun thing. We'll stop by and we'll ask you, are you sure about that? Don't assume that we're asking that because you're wrong.
If that is the right answer, because you have learned what is necessary to get that answer, then defend it. Defend it against us, and we'll be like, oh. Oh, right, yeah. OK. That looks right.
So we want to encourage you to stand your ground if you do understand it. If you don't understand it, take that opportunity to say, I don't know. And that's fine as well. That's that being stuck part, and we're here to help you get unstuck.
OK. So I think that is most of my first-day lecture condensed into about five or 10 minutes or something. There's much more that I would have to say. But I think for the demonstration that we're going to be doing today, the absolute best thing to do is to dive right on in.
So I hear that you've already been broken down into groups with letters. There are labels on the board spaces where you can work with your group on the problem. And the problem is on the worksheet that we have there. Can we get those handed out to everybody?
This worksheet is something that, about seven years ago, I was on a flight from Los Angeles to Boston. And for some reason, I just didn't have access to the internet, and I didn't have my computer available. And so I was on a six-hour flight kind of staring out the window. And I started thinking about fun problems that I could dream up. And this is one of the ones, my favorite ones, that came up.
This problem is hard. I very rarely had students take a look at this problem and say, oh, that one. I know how to do that one. This is going to require some thinking. It's going to require you to think carefully and communicate with the people in your group.
Don't feel bad if you don't even know how to start. But I bet if you talk through it enough, you're going to start finding the initial threads to start pulling on so that you can start putting together this fun little puzzle. And the goal today is that we want to use some household items to measure the mass and radius of the Earth, the mass and radius of the moon, and the distance to the moon. Sound fun? I know it's fun. So let's go ahead and dive in.
RACHEL: Do we want to just do a quick hello?
ALLISON PINGREE: Let's introduce each other. Yes. Yes.
RACHAEL: Well I'm Rachel. I'm at HUGSI part time, finished graduating this year. And I also work at the law school.
SPEAKER 2: I'm [INAUDIBLE]. I'm a PhD student at the Committee on the Study of Religion with a secondary in African and African-American studies. I teach as a teaching fellow on campus, but then I also am a part-time instructor at Northeastern as well.
ALLISON PINGREE: Fabulous. My gosh. I'm Allison Pingree. I'm the associate director for instructional support and development at the Teaching and Learning Lab. Work with Bill and Josh. So I am basically an instructional coach for faculty, but I also teach a course on essentials of coaching for our master's students.
DORIS: I'm Doris. I'm currently a student at HUGSI, a master's student. And before this, I was working in the k-12 context.

ALLISON PINGREE: Which program are you in?
DORIS: I'm in the learning design innovation and technology.
BILL RISS: So I'm Bill Riss. I'm the director of the Teaching Learning Lab here at the Ed School. And I also teach a course on applied learning design that Doris is in. OK.
ALLISON PINGREE: Excellent. excellent
RACHAEL: All right, well, let's delve into this.
SPEAKER 2: Feel very far removed from this material, so.
ALLISON PINGREE: So our final task is this stuff, right? Down here. These are the things we got to do.
RACHAEL: Right. And I think we're trying to figure out the scale of the Earth and the Moon because I was initially confused even with the question--
ALLISON PINGREE: Oh, you mean these things will help us to know the scale of the Earth and the Moon?
RACHAEL: Yeah.
ALLISON PINGREE: Oh, I see see.
SPEAKER 2: And the distance, right? Because he said, the distance from the center--
JOHN ASHER JOHNSON: Yeah. So when we talk about the scale, we mean like, how big are they, and how much do they weigh? So that's actually exactly what was listed down there.
ALLISON PINGREE: OK, yeah.
BILL RISS: So it looks like we have to determine two of the five.
SPEAKER 2: Oh, OK.
BILL RISS: So we may want to focus in on two. I don't know what parameters we would use to decide which two, but that may give us a little bit more focus.
RACHAEL: Wait, are you looking at this part, the two significant-- where are you getting the two?
ALLISON PINGREE: What I read that is that each of the answers needs to be rounded, rounded to two significant--
BILL RISS: OK, it could be. Yeah, I'll take that.
ALLISON PINGREE: That'd be great if we-- we all need to to pick and choose--
BILL RISS: All right, so we have to do all five then. All right.
SPEAKER 2: Yes, I agree. To two significant figures.
ALLISON PINGREE: But that's right.
RACHAEL: Does just two significant figures means two decimal points or does it mean 2.0?
JOHN ASHER JOHNSON: It basically means don't worry about precision too much. Round numbers are great. If you have around number with an additional digit, that's really cool. But don't go further than that.
ALLISON PINGREE: Because we wondered if it meant that we only needed to answer two of the questions.
JOHN ASHER JOHNSON: Oh. No, no. Yeah. Answer as many as you can and particularly as many as you feel particularly motivated to do.
ALLISON PINGREE: OK.
JOHN ASHER JOHNSON: Here's what I think would be a good place to start would be maybe a diagram on the board so that you guys can point to things. And with that diagram, it might start becoming clear that, OK, so where does this information map onto, let's say, a picture of the Earth? Is there a way that we

can take this apparently disparate pieces of information and put it onto the Earth in a way that helps us think through?

ALLISON PINGREE: OK.

JOHN ASHER JOHNSON: So I need one brave person who's willing to go to the board and write.

[LAUGHTER]

ALLISON PINGREE: Draw. OK.

JOHN ASHER JOHNSON: And maybe a couple of people to stand by that person to support them.

ALLISON PINGREE: I'm happy to just go and draw.

SPEAKER 2: All right.

BILL RISS: OK. So it seems to be-- the first two clues seem to be related to each other, right?

DORIS: Yeah. So that seems to help us find the radius of the Earth.

BILL RISS: Right. And maybe the moon if there's some way to make it comparable.

ALLISON PINGREE: Whoops.

RACHAEL: Can we just--

BILL RISS: It seems definitely-- excuse me. Sorry.

RACHAEL: I was just going to say, can we just have a brief reminder the radius is the halfway point between a circle, and it's two dimensional.

ALLISON PINGREE: This is a radius?

RACHAEL: That's--

ALLISON PINGREE: Circumference.

RACHAEL: the radius is from here to here, right?

ALLISON PINGREE: Correct. OK.

RACHAEL: OK. Just so we're all clear on what we're--

ALLISON PINGREE: Thank you.

RACHAEL: --measure the radius. So that would be the radius. OK.

DORIS: Yeah, that's really helpful. Thank you.

ALLISON PINGREE: Yeah.

DORIS: So yeah, that one seems pretty straightforward. If we can say about what is the speed of an airplane. Do you guys remember? Typical airplanes, how fast they fly?

RACHAEL: No. No idea.

DORIS: I want to say it's somewhere between 500 to 800 miles per hour. I'm trying to remember the last time I looked in the screen with all the stats when I was flying. Do you know how fast an airplane flies, Allison, Approximately?

ALLISON PINGREE: I don't. But how is that coming-- But wait, why do we want to know how fast an airplane flies? Are we thinking that the distance between LA and Boston is related to the radius of the Earth?

DORIS: That's what I thought.

ALLISON PINGREE: Oh, OK.

BILL RISS: It gives us a measurement point that, from coast to coast and just the basic United States is 3,000 miles. And we do know that it's from a time perspective. According to the time zones that we've created, that's three hours difference.

JOHN ASHER JOHNSON: I like your thinking is what I will say from here. Some good thinking. So on your diagram of the Earth, I'm wondering how you might take that information about time zones and put it onto that diagram? Where would it fit there? Because you're relating it to distance somehow.
BILL RISS: It feels like I need more data--
JOHN ASHER JOHNSON: For example, where can we put Boston on the Earth there? And where can we put LA? It's like two dots maybe.
DORIS: So let's say-- so right now, let's say we're just looking at the Western hemisphere on this side. So then Boston is here, LA is here.
RACHAEL: Maybe we should draw-- maybe we should draw that separately because now we've got this diagram representing two things, right? We've got it representing the whole Earth, but then we also have Boston and LA. So maybe we should have a separate diagram. Does that make sense?
DORIS: Here, draw it yourself.
RACHAEL: Or are you saying that the Western hemisphere is just here on the Earth? That's all I'm asking.
DORIS: Oh, yeah, I'm--
JOHN ASHER JOHNSON: We're looking at it from the side.
DORIS: OK. Yeah. Because then the eastern hemisphere is on the other side that we don't see is what I'm presuming. But if you have a different [INAUDIBLE].
RACHAEL: I'll work in 3D. Trouble, but I'll get there.
JOHN ASHER JOHNSON: I kind of your idea, though, is that if we-- you kind of have this we're looking at the side of the Earth and the Boston area. And coming around, we get the LA. Is that the way you drew it? Kind of like--
DORIS: Yeah. So this would be our flight path.
JOHN ASHER JOHNSON: Yeah, yeah, so on the side. But there's another way of putting it where we can have the circle for the Earth. And we can looking down at the pole. And we would see Boston over here and then some fraction of the way around.
RACHAEL: It'd be very small.
JOHN ASHER JOHNSON: I think either way, I think they each have merits. But the key is that you're trying to visualize what's going on.
RACHAEL: Trying to think how many 3,000 miles does the globe- how many segments of 3,000 would it take to go around the whole--
JOHN ASHER JOHNSON: I really like that--
RACHAEL: --whole globe is what I was thinking.
BILL RISS: I feel like the same way.
RACHAEL: But I had no idea.
BILL RISS: It feels like--
ALLISON PINGREE: That's great, though.
BILL RISS: It feels like--
ALLISON PINGREE: These estimates, no, that's great.
BILL RISS: It feels to me if this was the Western hemisphere, and we had the Atlantic Ocean over here, and we have the Pacific Ocean over here. So it feels like Boston to LA is more like that. But I don't have any data to say. So then time zone--

DORIS: Or I think what you're saying is key, right? Because we do know that. Because across the whole globe it's 24 hours, right? And we know that there's three hours. This is a three-hour chunk. So this--
RACHAEL: Ooh, nice.
DORIS: 3/24 of the globe.
RACHAEL: Wow.
DORIS: No, you--
[INTERPOSING VOICES]
BILL RISS: So if this is the three time zones between Boston and LA here, right? And then we have additional time zones going all the way otherwise around.
ALLISON PINGREE: When you say-- that's what you meant when you said 24 hours?
DORIS: Yeah. 24 hours around the globe. So the portion that we have, 3,000 miles is 3/24 of the circumference.
BILL RISS: Which is 1/8, right?
RACHAEL: This equals 3,000. 3,000 equals 1/8. So 8 times 3,000 would be the total, right?
BILL RISS: So 240,000 miles, is that right?
RACHAEL: Yeah.
BILL RISS: 24.
DORIS: Is that right?
BILL RISS: Yeah, 240.
DORIS: So then we can say the whole circumference of the Earth is 24,000 miles?
ALLISON PINGREE: Yeah, that's 12,000.
BILL RISS: So the radius is 12,000?
RACHAEL: Just remind me the difference between the diameter, the radius, and the circumference?
ALLISON PINGREE: Oh, yeah, circumference is all the way around. And diameter is--
RACHAEL: Diameter is-- diameter and radius are 2D, and circumference is 3D.
ALLISON PINGREE: That's the problem. That's right. And so the flight is happening on a circumference thing, whereas what we're trying to go through the middle. We're trying to do 2D. Yeah, you're right, circumference, radius, D.
BILL RISS: Yeah. Because 3,000 is 3D.
ALLISON PINGREE: 24. So how do we get from an arc to this straight line? C equals pi r squared.
DORIS: That is that right?
RACHAEL: C equals pi r square.
DORIS: Circumference is pi r squared? This is like way back.
RACHAEL: I'm really impressed with you. Gosh.
DORIS: Yeah. I don't know if that's right. Is circumference pr r squared?
BILL RISS: It sounds good to me. It looks good.
RACHAEL: Can we [INAUDIBLE]
BILL RISS: Be confident about it.
RACHAEL: Our standards--
DORIS: No, that's the area of a circle. Circumference--
RACHAEL: Wow, I stand in awe of your--
SPEAKER 2: I'm a religion major. I don't know.

[LAUGHTER]
ALLISON PINGREE: We're contemplating the meaning of all this.
SPEAKER 2: Yes, yes. And we're we're done, I will let you know what it all means.
DORIS: Maybe we're getting too stuck. Maybe we have another tool in here because when I was driving my car the other day, I looked at my speedometer and noticed I was going 100. Oh, wait, that was kilometers per hour.
After setting my digital speedometer back to miles per hour, I was only going 60. I don't know why he gave us that piece of information, but it feels--
ALLISON PINGREE: I think it's so that we can get a way to alter, to transfer from miles to metrics and thus use the Kepler--
DORIS: Nice.
ALLISON PINGREE: --the Kepler form.
BILL RISS: Which would allow us to break it into centimeters, right?
DORIS: All right. Right, we got to go metric.
BILL RISS: Yeah, we have to at some point go to metric.
ALLISON PINGREE: We can't look at our phones, right?
RACHAEL: We were wondering what the--
JOHN ASHER JOHNSON: What were you wanting to look up?
ALLISON PINGREE: The circumference formula.
JOHN ASHER JOHNSON: Oh, the circumference is 2 pi times the radius.
RACHAEL: 2 pi times--
JOHN ASHER JOHNSON: That's the area that you have there. So the circumference is 2 pi. Yep, yep, you have it.
RACHAEL: OK.
DORIS: All right.
JOHN ASHER JOHNSON: Whoa, whoa, you've done a lot since I was here last.
[LAUGHTER]
What did we do here?
RACHAEL: Doris.
JOHN ASHER JOHNSON: What have you done?
[LAUGHTER]
RACHAEL: Well, we figured out that this was 3,000. And then we figured out that--
BILL RISS: Yeah, somebody had come up with this, which was really groundbreaking.
RACHAEL: We figured out-- this was Doris who figured out we have 24 hours in a day, three hours for one time zone. So 3/24 equals 1/8. And then we sort of--
JOHN ASHER JOHNSON: Yeah, OK. That's 1/8 of the radius is 3,000.
ALLISON PINGREE: No, isn't it circumference, though? 1/8 of the circumference, not the radius.
JOHN ASHER JOHNSON: Oh, that's right.
ALLISON PINGREE: Because you're going around. We're flying.
JOHN ASHER JOHNSON: Thank you. Yeah, right. OK. So it's the circumference that you're 1/8 on. And that means that, OK, you have the formula there.
And the value of pi in this class is really convenient. It's 3.

ALLISON PINGREE: Oh, it's just 3? Not even 3.14.
JOHN ASHER JOHNSON: No. This class, it's just 3.
ALLISON PINGREE: Wow.
RACHAEL: So 2 times 3 times 24.
JOHN ASHER JOHNSON: Although, I don't know if the 24,000 goes there.
DORIS: Oh, that was the circumference.
RACHAEL: Oh, right.
BILL RISS: So how do we solve for r if we know the circumference and we know pi?
ALLISON PINGREE: Exactly.
BILL RISS: And we 2?
DORIS: 2 times 3 is 6. 24 divided by or--
ALLISON PINGREE: 4,000.
BILL RISS: Miles.
ALLISON PINGREE: Miles.
BILL RISS: All right.
DORIS: All right. And now--
BILL RISS: Now you need to convert the kilometers--
ALLISON PINGREE: But now it's centimeters.
RACHAEL: To this radius of Earth, he wants it in centimeters.
BILL RISS: So 4,000 times 0.6.
DORIS: But we have the conversion.
RACHAEL: Right. And we know--
ALLISON PINGREE: But isn't' that meters?
RACHAEL: But now, Allison--
BILL RISS: That's kilometers.
RACHAEL: --to your point, we know that that's 4,000-- we're still in miles, right?
ALLISON PINGREE: Yeah.
BILL RISS: So we need to times by 0.6.
RACHAEL: We need to--
DORIS: Right, because we have the--
RACHAEL: Right because we have too--
ALLISON PINGREE: Convert 60 to 100, OK. But then by--
BILL RISS: And then it's just a matter of taking off zeros.
ALLISON PINGREE: Or adding zeros to get to centimeters versus meters.
BILL RISS: Right, exactly.
ALLISON PINGREE: Wait, kilometer to centimeter is how many zeros? Kilometer is 1,000 meters. Centimeter is 100th of a meter. So five zeros. Add five zeros, I think.
RACHAEL: S0 100 kilometers.
ALLISON PINGREE: Oh, very good.
RACHAEL: Yeah.
DORIS: So then what's 400 divided by 6? Who's good at mental math?
ALLISON PINGREE: 4,000, you mean?

BILL RISS: No, because she took the zeros out.

ALLISON PINGREE: No, I know but you're timesing it. 400 times 100?

DORIS: 400 times-- yeah, so it's going to be 40,000 divided by 6 is--

RACHAEL: 5 something, or it's 6 times 6 is 36. And 6 times 7 is 42. So like, 6.5.

BILL RISS: Doris, can you put 4,000 times 0.6? It might be an easier way to do it.

ALLISON PINGREE: Oh, yeah. Let me just get rid of this pen because it doesn't work. I don't think it's--

BILL RISS: Because that'll get us at 60%.

DORIS: Is that what you're saying? But that would be if it was 6 over 10, and not 10 over 6, right?

BILL RISS: Well, it is. It's 60km equals 100 miles, right?

ALLISON PINGREE: No, 100--

RACHAEL: No, it's the other way around.

ALLISON PINGREE: 100 kilometers is equals 60 miles. Right. Kilometer is a shorter distance than a mile, right?

RACHAEL: Because we are 6 times 6 is 36. And 6 times 7 is 42. So it's like 6.6 more or less, 6.7. 6.7.

ALLISON PINGREE: Are you still thinking that we're

BILL RISS: No, maybe not--

ALLISON PINGREE: OK, because I'm still struggling with how to do that conversion. OK.

BILL RISS: I do not feel strongly with this position.

ALLISON PINGREE: Because 100 miles is 40,000--

DORIS: So we're at 6.7--

RACHAEL: 6.7 kilometers because the miles and miles cancel one another out.

DORIS: OK.

RACHAEL: That can't be 6.7.

SPEAKER 2: Oh, because we're multi-- OK. We're adding the zeros. Are you doing the centimeters?

DORIS: No, we're still on kilometers.

SPEAKER 2: Oh.

DORIS: She wants to do centimeters.

[LAUGHTER]

BILL RISS: We're trying to get to kilometers.

DORIS: We could actually-- we could just-- yeah, let's just do centimeters here. So 60 miles and then-- So there's 1,000 meters in a kilometer, right?

BILL RISS: Yes.

DORIS: 1 kilometer, 1000 meters. And then there's 100--

RACHAEL: Centimeters in a meter.

DORIS: All right, someone do this math. Now there's so many zeros going on.

ALLISON PINGREE: 3, 4, 5, 6, 7, 8, 9, 10. So it's 10. 4, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. 40 trillion.

RACHAEL: Divided by 60, right?

ALLISON PINGREE: Divided by 60. Right.

RACHAEL: And let's just make sure that all our units are canceling out, right? So kilometers to kilometers--

ALLISON PINGREE: Meters to meters.

RACHAEL: --miles to miles, meters to meters. So these are centimeters, but this is still--

DORIS: I have to do this. So kilometers to kilometers, miles to miles, meters to meters. All right, we're left with centimeters. I just needed to confirm that.
RACHAEL: Good. Then we can erase this 0 and then erase that 0.
DORIS: You know what? Can we show our work a little? Bit because if someone came over to us and said like, how did you go from to that to that, I'd be like, I'm not sure. I'll think of something. Yeah, there we go.
ALLISON PINGREE: So then I can go like that and like that.
DORIS: Yeah.
ALLISON PINGREE: And then so--
BILL RISS: 6 into 40 is 6.
RACHAEL: 6.67 is what we--
DORIS: So 400 divided by 6 is 67.
SPEAKER 2: Was it supposed to be 10 0's?
ALLISON PINGREE: Yeah, isn't that right? So because 1, 2, 3, 4, 5, 6, 7, 8, 9, 10?
RACHAEL: Here, should we just write it out even though it's-- that's 1, 2, 3, 4, 5, 6, 7, 8, 9. 4, 5, 6, 7. 6. not
ALLISON PINGREE: 67 with one less 0?
BILL RISS: Yes. That's what I think.
ALLISON PINGREE: So 67 with eight 0s?
RACHAEL: OK. And this was 6 centimeters.
BILL RISS: Yeah.
ALLISON PINGREE: So 6 billion 700 million. No, 6 trillion 700 billion--
RACHAEL: That's 1 million--
BILL RISS: That's billion, you're right.
RACHAEL: --6 billion.
ALLISON PINGREE: 6.7 billion centimeters.
BILL RISS: 6.7 billion centimeters. Yes.
RACHAEL: 6.7 billion.
SPEAKER 2: And what is the period of a planet again?
ALLISON PINGREE: What's the what?
SPEAKER 2: The period of a planet?
DORIS: You're talking about the Kepler thing?
SPEAKER 2: Mm-hmm.
RACHAEL: And so this is the circumference of the Earth in centimeters, right? Which we're saying is a whole--
DORIS: The radius?
ALLISON PINGREE: No, it's the radius.
RACHAEL: The radius. OK.
ALLISON PINGREE: Yeah. So it's answer to number one.
[LAUGHTER]
Yay!
BILL RISS: Good job, team. Should we stick width distance or go with weight for another one?

ALLISON PINGREE: Right, right. Because how would we get radius of the moon if we hadn't done some of the other stuff, right? Because we don't have any--
DORIS: Yeah, I don't know what the period means either. Does anybody understand that? The period of a planet, what is the period of a planet? Is it it's like Joseph Kepler?
BILL RISS: Well, the moon's not a planet. I was thinking like the waxing and waning of it.
RACHAEL: You know, I just look at that sentence, and my brain shuts off.
[LAUGHTER]
It's like I can't even process it all. I'm like, oh, my god. I'm like, give me a word like epistemology, and I'm ready to go all in.
ALLISON PINGREE: Right. We can ask.
SPEAKER 2: I am developing some compassion for my STEM students, though, who have to learn religion. I'm like, wow, this is what it's like for them.
ALLISON PINGREE: Yeah, right. What is meant by the period of a planet? What is that?
JOHN ASHER JOHNSON: The period is the amount of time it takes for it to complete one orbit. So you're going all the way around. And Kepler's law applies to one massive object floating in space, orbiting around another massive object. So that's the setting where you want to use Kepler.
RACHAEL: So the moon is floating around the Earth.
JOHN ASHER JOHNSON: Yes.
ALLISON PINGREE: So the period of the moon is proportional to its distance.
JOHN ASHER JOHNSON: So you have the-- what do you have so far? You have the radius?
ALLISON PINGREE: Yeah.
JOHN ASHER JOHNSON: And we're working on now the Mass?
ALLISON PINGREE: Yeah.
JOHN ASHER JOHNSON: OK. Yeah, so this is the fun part. The mass of the Earth is going to be related to this sort of a thing.
ALLISON PINGREE: Because this is rock scale beaker.
JOHN ASHER JOHNSON: Yeah, this is kind of like a rock.
ALLISON PINGREE: That's the rock. OK.
JOHN ASHER JOHNSON: We actually have some-- we have some actual rocks.
ALLISON PINGREE: I saw that. Yeah.
JOHN ASHER JOHNSON: So if I had a piece of rock, what am I holding? It's one way that for this problem, a tiny fraction of the mass of Earth. Yeah. Yeah. I actually have a piece of the Earth that has mass, right?
And so if I-- how would the mass of this rock relate to the mass of the Earth? If we know the general size of the Earth and we know the general size of the rock, we can extrapolate, perhaps? The bigger, the rock the bigger the mass.
So there's that kind of a ratio that you could set up, right? So we could do mass of the rock compared to the mass of the Earth. And then we'd have something about size is another ratio. We have to pick the right thing for the size.
ALLISON PINGREE: You mean the right rock?
JOHN ASHER JOHNSON: No. The right quantity.
BILL RISS: So we measure like this the centimeter of the rock in some sort of volume-based way.

ALLISON PINGREE: Oh. That's why we need to know the radius of the Earth.
JOHN ASHER JOHNSON: Yeah.
ALLISON PINGREE: Ooh.
JOHN ASHER JOHNSON: I like what you're thinking. Yeah. So keep thinking that way.
ALLISON PINGREE: Ooh.
BILL RISS: All right, what's the formula for volume?
DORIS: The three things, right? We're doing circles never mind. I was off on boxes. And Yeah, yeah, yeah, yeah, it's the wrong shape.
BILL RISS: Right.
DORIS: So Bill, you're saying if we can find the volume of this, then we can compare it to the volume of the Earth, is that right? And then extrapolate--
BILL RISS: I think we have some data. I don't know if we have all the data to be able to do that extrapolation if we knew-- if we knew the size of the rock and then were able to equate that to volume, which is a measurement that allows us to predict mass.
ALLISON PINGREE: How does volume relate to mass? Mass is weight.
DORIS: It's related by density, though. And how do we know that the density of that is comparable to the density of Earth?
BILL RISS: That is Earth?
DORIS: Oh, this is supposed to be Earth. OK. I see.
ALLISON PINGREE: So we're pretending that's a piece of the Earth.
DORIS: OK. OK.
BILL RISS: Tiny fraction of Earth.
RACHAEL: Not at scale.
BILL RISS: But if we don't have the formulas, I don't know how to even start.
DORIS: Let's weigh the rock.
BILL RISS: So we have weight, and we have the-- what's that called?
RACHAEL: The beaker.
ALLISON PINGREE: Beaker.
BILL RISS: Where you put it in. And then--
ALLISON PINGREE: Oh, so then we can find the volume.
DORIS: Right.
RACHAEL: So, oh and you can do that by measuring this first and then--
BILL RISS: Yeah, measure the weight first.
RACHAEL: What unit do we want to use, though?
ALLISON PINGREE: Let's stick with the grams metric.
DORIS: 120 grams?
BILL RISS: And we're starting off with 350 milliliters. I found some rock.
SPEAKER 2: Oh, a rock.
RACHAEL: Oh. Thank you.
BILL RISS: And now we need to weigh that. This is relevant. And your answer will be more precise if you can figure out how to use this along with your rock.
DORIS: OK. So we have 120, and we have 200.

RACHAEL: OK, 200 grams.
ALLISON PINGREE: 200 grams--
DORIS: Is the rock. And then--
ALLISON PINGREE: 120 was the--
DORIS: Washer.
RACHAEL: Yeah, a giant washer.
DORIS: Giant washer.
BILL RISS: It's a nut.
RACHAEL: And we have 350 milliliters.
SPEAKER 2: We are at 3--
BILL RISS: 375 or 360?
ALLISON PINGREE: Looks like about half way. no, no, it's--
BILL RISS: So 10 milliliters?
DORIS: So then that is 10 milliliters?
ALLISON PINGREE: Yeah.
SPEAKER 2: Yeah. That's about-- actually, I don't know.
BILL RISS: Let's go to round numbers.
SPEAKER 2: It's good enough.
ALLISON PINGREE: Let's try the rock now. Rock would be a big volume, you think or smaller than that point?
BILL RISS: Bigger because it's solid, I would think.
SPEAKER 2: Oh, yeah, it's at 400.
ALLISON PINGREE: So it's 50.
JOHN ASHER JOHNSON: One piece of information that's not on the worksheet is that 1 milliliter is equal to 1 cubic centimeter.
SPEAKER 2: Oh.
ALLISON PINGREE: Oh.
SPEAKER 2: 1 milliliter.
BILL RISS: If we knew at the beginning--
[LAUGHTER]
ALLISON PINGREE: we Would have been done by now.
[LAUGHTER]
JOHN ASHER JOHNSON: OK. I'll have a revised worksheet soon.
DORIS: So what was the volume of the rock?
SPEAKER 2: 400. Oh, 500.
ALLISON PINGREE: 50. Sorry, it's 50.
BILL RISS: 50 milliliters.
RACHAEL: And then he told us 1 milliliter is equal to 1 centimeter cube. So is that 50 divided by--
ALLISON PINGREE: So it's-- no, it's times.
RACHAEL: So 50 times-- 50 milliliters times 50 cubed, right?
ALLISON PINGREE: I don't know.
RACHAEL: I'm just saying. I mean, I was just saying, I was taking this. 50ml equals 50, right?

BILL RISS: 50 times 50 times 50?
RACHAEL: That's all I was doing. Nothing exciting. But is that right?
DORIS: Yeah, that's right. That's right.
RACHAEL: What is that?
DORIS: So density is mass over volume. So we're saying the rock is representative of the Earth.
RACHAEL: Oh, but I see what you're doing. 50 times 50 times 50 because we want to get-- we want to get rid of this cubed.
BILL RISS: Yeah, to get to centimeters.
ALLISON PINGREE: Wait, where did this thing about density come from?
DORIS: Well, so we're assuming that the rock is the Earth, right? So then the rock has the same density as the Earth. So we can compare the two.
ALLISON PINGREE: But why we talking about density rather than mass?
SPEAKER 2: Because if we get D, we we'll be able to find M, Right?
ALLISON PINGREE: Yeah. But how did you know that? You just knew that from before?
DORIS: Yeah.
ALLISON PINGREE: Oh, OK.
[LAUGHTER]
RACHAEL: In your past life.
ALLISON PINGREE: I didn't see anything in here about density. OK, you're right about that.
SPEAKER 2: No, I'm just lucky that worked.
ALLISON PINGREE: Yeah, exactly. Mass.
DORIS: OK. So then we know that the mass of the rock is 200 grams divided by 50 milliliters. And then the conversion is 1 milliliter is 1 cubic centimeter. But what unit do we want this in?
BILL RISS: Grams, ultimately. Well, for the mass, we want grams for the--
JOHN ASHER JOHNSON: Grams per cubic centimeter is good.
DORIS: OK.
RACHAEL: Oh, really? Grams per cubic centimeters is OK?
JOHN ASHER JOHNSON: Yeah, that's the way an astronomer would it.
RACHAEL: OK. Well, of course.
JOHN ASHER JOHNSON: Any astronomer worth their salt. A chemist would not agree. A physicist would not agree. Yeah.
DORIS: So then now we have to transfer that over for the Earth to figure out.
RACHAEL: Wow. So we're saying 6. Billion times 6. Billion times 6.7 billion? Is that what that--
ALLISON PINGREE: It's the medius.
SPEAKER 3: One-minute warning. One-minute warning.
DORIS: Wow.
ALLISON PINGREE: My gosh.
RACHAEL: We only have one answer. I feel like that was a win.
DORIS: That was a win.
ALLISON PINGREE: I mean, wow--
BILL RISS: It looks all official.
SPEAKER 2: We have have 1.75.

BILL RISS: Mass and radius of the Earth is what we were expecting for today.
ALLISON PINGREE: OK. But wait--
BILL RISS: Yeah, we didn't to the mass yet.
ALLISON PINGREE: We haven't done mass yet. So--
RACHAEL: Let's not be the Harvard students that we're always criticizing the Harvard students for, right? That we're frustrated that we haven't gotten all the answers. But instead, think about how much progress we've made. So when all looked at this, we were like, no way.
[LAUGHTER]
SPEAKER 2: Yeah, that's true.
BILL RISS: That's true.
RACHAEL: Let's walk the talk.
DORIS: I feel like we're almost there, though--
RACHAEL: I do.
DORIS: --with tho one.
RACHAEL: I feel like we have another half an hour.
BILL RISS: Yeah, how do we convert this-- yeah, how do we convert this to--
RACHAEL: That's the total amount of time we were given.
I mean, if you know that 6. Billion centimeters is the equivalent to r, where is r in our formula? Where is r elsewhere? Or how do we get to r? Or where else is r? Or what is r? Do you know what I mean?
DORIS: Yeah. So I think the next key is we'd have to figure out what is the volume of a sphere to relate it to r.
ALLISON PINGREE: Are we leaving out-- I mean, this Kepler thing, we haven't used either of these clues.
DORIS: I think we're trying to get-- because we need m, mass. So we haven't even figured out m. So we can't--
ALLISON PINGREE: What is the mass of the central body? I think we'd have to engage this fourth clue.
I think we are out of time.
RACHAEL: Nice work, team.
BILL RISS: OK, I learned something, I think.
SPEAKER 4: OK. We have this [INAUDIBLE]. So we have a rock, a scale, a beaker. Where's the scale? Oh, that's the scale.
SPEAKER 5: Sorry, my lack of English. Which one is beaker?
SPEAKER 4: That's beaker. Yeah, and that's a scale.
SPEAKER 6: And that's the rock.
SPEAKER 4: Thank you.
SPEAKER 7: They didn't say anything about this. That's interesting. It's a big nut of some kind.
SPEAKER 6: Yeah.
SPEAKER 4: OK. So we have to measure the quantities, right?
SPEAKER 7: Mm-hmm.
SPEAKER 8: The radius of the Earth, the mass of the Earth.
SPEAKER 7: So the radius of the Earth and the mass of the Earth in grams?
[LAUGHTER]

That's going to be fun. The distance from the center of the Earth to the center of the moon. The radius of the moon and the mass of the moon. OK.
SPEAKER 8: Can we get the circumference by just using the first two clues and then get the radius from that?
SPEAKER 6: Yeah.
SPEAKER 7: And then figure out-- oh, that's a good idea.
SPEAKER 8: Because if it's three hours in between, are there 24 time zones? Am I making this up? Are there 20 more?
SPEAKER 7: No, I don't think--
SPEAKER 6: I need to write that on here.
JOHN ASHER JOHNSON: You know, what I mean because if it's--
SPEAKER 7: OK. Thanks for teaching. Is it important for us to leave the board where it's set for the sake of--
JOHN ASHER JOHNSON: Yeah, but it's OK to gather around. So these areas will be filmed.
SPEAKER 8: So for you--
SPEAKER 6: So [INAUDIBLE] 24 time zones?
SPEAKER 7: Oh, I see you.
SPEAKER 8: Well, there are 24 time zones.
SPEAKER 6: So it arcs like over here? Yes.
SPEAKER 8: Each time zone is 1,000 miles? Because they cross times more--
SPEAKER 6: Right.
SPEAKER 8: So then it would be the radius-- or the circumference would be--
SPEAKER 7: And because we assume that from Greenwich all the way around, from Greenwich Mean Time is 24?
SPEAKER 8: I'm wondering if that's true, to be honest with you. I think it is.
SPEAKER 7: It feels like a pretty good guess to me. So it'd be 24,000 miles?
SPEAKER 8: So then the full circumference would be another 24,000.
SPEAKER 5: You know, so when I think about it, that feels about right because I think it takes about as long to fly from Boston to San Francisco as it takes to fly from San Francisco to Hawaii, right?
SPEAKER 8: About 53,000 miles-ish.
SPEAKER 7: Yeah. That makes sense. And so that's six. That's like covers a quarter, at least.
SPEAKER 8: And we can get the radius, right? Because the circumference is pi r squared?
SPEAKER 5: Pi r.
SPEAKER 8: Pi r squared or 2 pi r?
SPEAKER 7: It's been a long time since I thought about that.
[LAUGHTER]

SPEAKER 5: And pi r squared is the area.
SPEAKER 8: OK. I think that's right because it's a squared.
SPEAKER 7: So that would be--
SPEAKER 8: And then so then divide by 24 or 12,000 over pi.
JOHN ASHER JOHNSON: Can I pause for a second?

SPEAKER 8: Yeah.
JOHN ASHER JOHNSON: I'm curious. So we didn't give you the circumference of the Earth, right?
SPEAKER 5: No.
JOHN ASHER JOHNSON: How did you get that?
SPEAKER 5: Well--
SPEAKER 7: For some good hypothesizing.
JOHN ASHER JOHNSON: Yeah.
SPEAKER 7: Go ahead. Go ahead, Patrice.
SPEAKER 5: We were guessing that based on 3,000 miles in three hours, that it was approximately 1,000 miles per time zone. And if there's 24 time zones, then--
SPEAKER 7: That was a guess.
SPEAKER 5: That was a guess.
JOHN ASHER JOHNSON: Oh, OK.
SPEAKER 4: That was how we came up with 24,000 miles.
JOHN ASHER JOHNSON: I like that. OK, great. So then you're already at this point where you're writing down some math. Let me give you a little secret of this particular class. The value of pi in astro 16 is 3.
SPEAKER 7: Oh. OK.
SPEAKER 5: Makes the math easy.
JOHN ASHER JOHNSON: That' about the level of precision that we want to work with.
SPEAKER 5: That's awesome.
JOHN ASHER JOHNSON: We want approximate answers because the process is much more important than the product, right?
SPEAKER 5: Right.
JOHN ASHER JOHNSON: So great.
SPEAKER 7: Really helpful. Thank you.
SPEAKER 4: So you're almost--
SPEAKER 7: So we got-- oh, wait that was not--
SPEAKER 8: Pi equals 3
SPEAKER 5: Pi equals 3. Equals--
SPEAKER 4: 3r.
SPEAKER 5: 3r, right? So r equals 4,000?
SPEAKER 4: 4,000. Wow.
SPEAKER 7: OK. So just to check my understanding, that means that from where we stand to the center of the Earth?
SPEAKER 4: Yeah.
SPEAKER 8: To the other side.
SPEAKER 7: 4,000 miles, right? Just to the center because you just get us that, right?
SPEAKER 5: Yeah.
SPEAKER 7: I'm just checking because it's been a long time since I thought about radius. OK, cool. Thank you. OK.
SPEAKER 4: So we've got the radius. Now we have to get the mass of the Earth.

SPEAKER 5: Oh, wait, wait, wait, wait, wait, wait, wait. They want the answer in centimeters. And this is not something-- then we have to convert, right? we
SPEAKER 8: So then you just do this for conversion.
SPEAKER 5: No, less than that.
SPEAKER 8: It said 100 kilometers for 60 miles. So if we times it by-- And it's like I was speeding it up from there [INAUDIBLE]
SPEAKER 5: Wait, say that again?
SPEAKER 8: [INAUDIBLE] let's take off the 0s. So that makes 6 and 10. 20,000 divided by 3.
SPEAKER 5: 6.66. And we get the repeating 6.
SPEAKER 8: So maybe 6.667? 3. Actually, so--
SPEAKER 5: This is 8.
SPEAKER 4: 667 point something.
SPEAKER 5: Bring the 2 down. Right.
SPEAKER 8: 6,66 something.
SPEAKER 7: That'd be it roughly?
SPEAKER 8: Sure.
SPEAKER 7: Right.
SPEAKER 8: And then times that by 1,000. No, because that was in kilometers.
SPEAKER 7: Oh, you're right. It's kilometers And then we have to convert to centimeters?
SPEAKER 5: Right.
SPEAKER 8: So 6 million--
SPEAKER 5: We're OK with 0s.
SPEAKER 7: Is that right?
SPEAKER 8: Yeah.
SPEAKER 5: Right. It's a big number.
SPEAKER 9: It's a big number.
[LAUGHTER]
SPEAKER 5: That's pretty awesome.
SPEAKER 9: OK. So I looked over and I saw that Professor Johnson had already been talking to you a little bit. Would one of you mind telling me very briefly what your thought process was for this?
SPEAKER 7: Sure, I'll let somebody else do it this time.
SPEAKER 9: Sure, that'd be great.
SPEAKER 7: I'll give it a try. So to back me up, everyone, and see if this right. OK, do you want from the beginning, or do you just want--
SPEAKER 9: Yeah, that's OK.
SPEAKER 7: OK. So--
SPEAKER 9: So maybe with the first thing I ask is, what were you solving for?
SPEAKER 7: We were trying to get to the radius. That was our first goal.
SPEAKER 9: Yeah, that sounds great.
SPEAKER 7: So we took the first statement, 3,000 miles from Boston to LA. We thought that takes-- there's a three-hour time difference. That's about 1,000 miles per time zone.

We took a good guess that there were 24 time zones. And that got us to 24,000 miles. It's the full circumference.
SPEAKER 9: Yeah.
SPEAKER 7: Yes.
SPEAKER 9: Yeah, that sounds good.
SPEAKER 7: And then we solved for it to find the radius, 2 pi r. And we got the information that pi is 3 for the sake of our work here. And then we came up with 4,000 miles and then realized, oh, it asks in centimeters. So we did the calculation to get to kilometers and then went from kilometers to centimeters. Does that sound right? OK, perfect. So you're all happy with this?
SPEAKER 9: Yeah, that sounds great. OK, so why did you say 24 times on this?
SPEAKER 7: Guessing?
SPEAKER 4: Yeah, it was a wild guess that we had.
SPEAKER 9: OK, yeah, but why the number 24?
SPEAKER 7: 24 hours in a day.
SPEAKER 9: OK, yeah, I like that. That sounds great. OK. And then let's see, so I like this unit conversion here with the kilometer to miles. The final answer, how did you get from this kilometers to centimeters answer?
SPEAKER 6: We timed 1,000.
SPEAKER 8: And we need to times it again.
SPEAKER 5: I mean, that's how I want-- yeah, we just time 1,000. So that's why we got 6,000 to 6--
SPEAKER 9: Yeah, OK. Right. So you're saying between that line to that line, that's a difference of-- that's a factor of 1,000? OK. But where did you get the 1,000 from?
SPEAKER 4: 1,000?
SPEAKER 9: You should go ahead and write on the board if you want. saying
SPEAKER 4: So are you saying from kilometer to centimeter, how did you get here?
SPEAKER 9: Yes.
SPEAKER 4: We know that 1 kilometer is equal to 1,000 centimeter. And we just multiplied the 1,000 here.
SPEAKER 9: So there's an extra factor, which I think-- I see your name is Justin.
SPEAKER 8: Yeah.
SPEAKER 9: So Justin, that's what you were saying. Would you like to maybe write on the board?
SPEAKER 8: So I think it's--
SPEAKER 7: We didn't show our work.
[LAUGHTER]
SPEAKER 5: Yeah.
SPEAKER 9: Well, you did show lovely work. And I could see where you got from one number to centimeter.
SPEAKER 5: Oh, I see we get to-- the we go to meters first and then to kilometers. And that gets us to the--
SPEAKER 8: So we just need to times it by 100, I think, right?
SPEAKER 9: OK. So why 100?

SPEAKER 8: Because we got it to meters. This is meters. And then there's a 100cm in every meter. So then if we just--
SPEAKER 4: Now we are on centimeters.
SPEAKER 9: OK, right. Yeah, that sounds great. Right, so the prefix kilo is for 10. Well, I think of it as 10 to the 3, but it's a factor of 1,000. Centi is a factor of 100 smaller.
So yeah, as he said, then there's-- if you think of it as 1 kilometer, it's 10 to the 5. 100,000 centimeter is great. But I don't think that way. I would definitely think convert to meters and convert to centimeters. Yeah. So that's all that's great. Thank you for explaining that.
SPEAKER 7: Thank you.
SPEAKER 4: Thank You.
SPEAKER 7: I know. This one feels a little-- so I wonder if anyone remembers anything about finding mass?
SPEAKER 5: So it must be the last clue, right?
SPEAKER 6: The is planet proportional to its distance.
SPEAKER 8: I think we can find the mass of this rock by putting it in the water and seeing how much of this increases. I don't know how to make the rock [INAUDIBLE].
SPEAKER 7: Let's see, how do we do that proportion of that?
SPEAKER 5: Well, maybe with the--
[INTERPOSING VOICES]
SPEAKER 5: We could measure the circumference of the rock. We know the circumference of the Earth.
SPEAKER 4: And then we can get the ratio of it and then calculate the ratio of the displacement.
SPEAKER 7: And then use it proportionally to figure out-- that all sound so simple, as we say.
SPEAKER 8: I know.
SPEAKER 6: And we've got this.
SPEAKER 4: So let's measure the-- so what we need to do is we need to have the mass of it. Should we do it on the board?
SPEAKER 5: Yeah.
SPEAKER 4: Yeah?
SPEAKER 5: Yeah.
SPEAKER 4: Let's do it with a different color. So we're on mass of the Earth. That's what we have to find. And we know that the mass of rock exists. We have the diameter. Should we get the diameter or the radius?
SPEAKER 5: Well, we have the radius, but--
SPEAKER 4: Let's get the radius.
SPEAKER 5: But it feels like it'd be--
SPEAKER 4: Diameter would be better?
SPEAKER 8: I mean, how do we get the radius?
SPEAKER 7: One degree.
SPEAKER 5: That's a degree angle, though. That's not going to help us. But we do know that part of my thumb is about an inch.
[LAUGHTER]
I remember that from somewhere, too. Like my arm is a like a foot.

SPEAKER 9: So the astronomical rule of thumb is like [INAUDIBLE] arms length.
SPEAKER 7: Oh, wait, we know this.
SPEAKER 6: Yeah.
SPEAKER 7: Do we know how big this is?
SPEAKER 6: Oh, do you think this one is one ?
SPEAKER 4: We can actually use that to displace, right.
SPEAKER 8: I don't know.
SPEAKER 6: I feels like this one side is an inch, no? Is that too small?
SPEAKER 5: Is there something embedded in this clue that might be helpful to us? Johannes Kepler found that the period of a planet-- I don't even know what that means with the period of a planet. What does that mean?
SPEAKER 8: It's like the way it goes around. It's not a complete circle. It's like an ellipses around the sun.
SPEAKER 5: So they're talking about the orbital period, how long it takes to orbit, OK.
SPEAKER 8: I think so.
SPEAKER 7: Now that the period of a planet is proportional to its distance from the central mass. So distance from the sun in this case. I have no idea what that formula is. Modified this to be--
SPEAKER 4: What is GM? Gravitational mass where m is the mass of the central body. And this is the gravitational mass.
SPEAKER 7: Well, we could wait we could weigh the water in the beaker.
[LAUGHTER]
Can we just do it and see?
SPEAKER 5: All right, so that's 363 grams.
SPEAKER 4: But it's a great idea to get the ratio of it because I really like the idea of ratio because if we have the ratio of that--
SPEAKER 6: This?
SPEAKER 4: Yeah. So if you have the diameter of that, we have the diameter of the Earth. And we can get the mass of that because it's proportional.
SPEAKER 8: I think this last clue is telling us we have to find--
SPEAKER 9: Do you think we could do the moon and work backwards?
SPEAKER 8: I think that's what it's trying to get us to do. Because if we can do the moon, then we know p. Then we can get m.
SPEAKER 5: Oh, OK, that's interesting.
SPEAKER 9: But I don't know how to use this last clue.
SPEAKER 5: OK.
JOHN ASHER JOHNSON: Can I offer a hint?
SPEAKER 4: Yes, please.
JOHN ASHER JOHNSON: What does this represent, this rock? What is the significance of it if we're talking about the--
SPEAKER 6: Any object on the Earth?
JOHN ASHER JOHNSON: So it could be just any object on the Earth.
SPEAKER 5: It has a mass.
JOHN ASHER JOHNSON: It has a mass. I like this. That's good thinking. Where does this come from?

SPEAKER 4: It also has a weight.
SPEAKER 8: The Earth.
JOHN ASHER JOHNSON: Yeah, this is--
SPEAKER 4: This is a piece of Earth.
JOHN ASHER JOHNSON: Yeah, this is a piece of Earth.
SPEAKER 7: M So it's about as dense as an Earth would be.
JOHN ASHER JOHNSON: Yeah. I like how you are thinking there. All right, so if I have something that has the same density of the Earth, then-- and what is the density related to of an object? It's two different things about an object that determine its density.
SPEAKER 4: The mass and the person--
JOHN ASHER JOHNSON: Weight, mass.
SPEAKER 4: Yeah. So weight is the gravitational pull along with the mass.
JOHN ASHER JOHNSON: So this is the mass. Yep. And also?
SPEAKER 5: And then the weight, how much--
SPEAKER 8: The volume?
JOHN ASHER JOHNSON: Volume. Yeah, yeah. It's just like how much of it.
SPEAKER 5: Yes.
JOHN ASHER JOHNSON: And if I have the volume, then I also have basically a fundamental dimension of this thing if it's a sphere.
SPEAKER 7: So we started thinking like, could that be-- if we could proportionally figure out that, could we then calculate proportionally what the Earth is?
JOHN ASHER JOHNSON: Yeah.
SPEAKER 7: We weren't sure how we could get an accurate read on either the diameter or the radius of that so that we could do that proportional thing, just guesstimate.
JOHN ASHER JOHNSON: But one of the nice things about radius or diameter or dimension is that it's directly-- you can actually relate it directly to volume. And you have a way of measuring volume right here at the table.
SPEAKER 8: Right. By submerging it.
SPEAKER 10: So we'll know the volume of that, but how do we move from that to--
SPEAKER 4: The volume of the Earth?
JOHN ASHER JOHNSON: How would you get the volume of the Earth? What's the shape of the Earth?
SPEAKER 4: A sphere.
JOHN ASHER JOHNSON: A sphere.
SPEAKER 4: So it's the volume of the sphere, right?
JOHN ASHER JOHNSON: So the volume of a sphere is related to what for a sphere?
SPEAKER 8: It's the radius.
JOHN ASHER JOHNSON: It's related radius cubed. Yeah, so it's 4/3 pi r cubed is the volume of the Earth. And you have that.
SPEAKER 7: Yes. We could calculate that based on this.
JOHN ASHER JOHNSON: You just did. Yep. So you have that.
SPEAKER 5: So this time- so we don't technically do the mass, we do the-- no, we don't do the radius. We do the volume.

JOHN ASHER JOHNSON: Yeah.
SPEAKER 5: OK.
JOHN ASHER JOHNSON: This is good. Glad I was able to supply some nice clues.
SPEAKER 7: Yes, thank you.
SPEAKER 5: We appreciate that.
SPEAKER 4: SPEAKER Yeah, because it's not like a perfect sphere.
SPEAKER 7: Wait, could we just go straight to volume then of the--
SPEAKER 4: So we have the r of the Earth.
SPEAKER 5: So we could definitely find the volume of the Earth.
SPEAKER 7: And then we have to get from volume to mass. Is that right.
SPEAKER 5: I think so.
SPEAKER 7: Because if volume is-- wait, what did you just say about the relationship between them?
SPEAKER 8: Volume is related to mass in terms of if it takes up-- if we submerge the rock, and it takes up 50 milliliters, that's 50G Because every milliliter of water is a gram. And a gram the unit of mass I think we're getting at.

But I'm still a little confused, to be honest. But we can just try it. We can just submerge it.
SPEAKER 5: And we can find the volume of the Earth. We can do that.
SPEAKER 4: Yes.
SPEAKER 8: We can do that. Yeah.
SPEAKER 7: Right. And so what we need to do is we need to get to the mass of the Earth. So if we can get to volume and then figure out what the relationship is between volume and mass, and we have the mass of that, then we'd be able to get to the mass.
SPEAKER 8: Or we can get to the mass by just weighing it, right
SPEAKER 4: Yeah.
SPEAKER 8: OK. And then we can get to volume by submerging it.
SPEAKER 6: OK.
SPEAKER 4: And then we technically get the mass of the Earth.
SPEAKER 8: Oh, OK, that's the missing--
SPEAKER 5: Is there an on button here that we need?
SPEAKER 7: It worked--
SPEAKER 6: Oh maybe this is the--
SPEAKER 5: Oh, there we go. so 199g.
SPEAKER 8: 199?
SPEAKER 5: Can we just call it 200?
SPEAKER 8: Let's do 200. We call it pi 3.
[LAUGHTER]
SPEAKER 6: Exactly. Like, we've already gone down that road.
SPEAKER 7: 200 grams.
SPEAKER 8: And then if we submerge it in the water-- so it's at 250 right now. And now it's at 300.
SPEAKER 7: Oh, it's perfect.
SPEAKER 8: So, 50.
SPEAKER 7: Perfect.

SPEAKER 5: We like round numbers at this table.
SPEAKER 8: Me, too.
SPEAKER 4: OK, sorry what was that?
SPEAKER 5: So 50 milliliters, right?
SPEAKER 7: Is the volume. No.
SPEAKER 8: Is the volume, yeah.
SPEAKER 7: Is the volume.
SPEAKER 8: It's how much space we'll displace.
SPEAKER 4: Is it milligrams?
SPEAKER 8: It's milliliter.
SPEAKER 4: Milliliter. So how do we look at the units then, because they are different?
SPEAKER 8: Well, let's see what ends up crossing off first.
SPEAKER 5: Oh, technically, can we cross off the units?
SPEAKER 8: Because we're going to go to cross out grams.
SPEAKER 7: Once we get the mass of the Earth, grams, right?
SPEAKER 5: But mass of the Earth is what we have to find.
SPEAKER 8: OK, we're not going to cross off grams. We're going to able to cross out--
SPEAKER 5: But we can cross out the volume of the Earth.
SPEAKER 8: Once we find it.
SPEAKER 5: Yes. So let's do this. It's pi 3 again?
SPEAKER 7: 3.
SPEAKER 5: And r is--
SPEAKER 7: Can we do it in miles?
SPEAKER 5: Maybe we should do it in kilometers and then convert to centimeters once we get to the end. I don't know if that would--
SPEAKER 6: Or we can call it 7.
SPEAKER 8: I like that.
SPEAKER 6: Oh, yeah, I like that. Can we call it 7 instead of 66--
SPEAKER 5: No, that's a-- I like--
SPEAKER 4: 700? You want to round off to 700?
SPEAKER 7: 667--
SPEAKER 4: But this is-- It's complicated.
SPEAKER 5: Radius cubed. That's right. Pi is 3.
SPEAKER 7: The 3's cross out.
SPEAKER 5: I really feel that we have to be mindful of the units that we are taking.
SPEAKER 8: Is that 7 centimeters?
SPEAKER 5: This is in centimeters. Do we want to go ahead with centimeters?
SPEAKER 7: Yeah, let's go ahead and leave it with centimeters. That's a great idea to shorten it up like that.
SPEAKER 6: That's 10 to the 8. That's to the 18th.
SPEAKER 5: I'm going to use the same thing to see--
SPEAKER 7: Whoa. I appreciate what you did there, and I don't understand it.

SPEAKER 5: So it's 10 times 6, right?
SPEAKER 7: Oh, got.
SPEAKER 4: So technically, this is-- and 6 plus 6 plus 6 would be 18 .
SPEAKER 7: Thank you. Thanks.
SPEAKER 8: OK, I think-- it's a milliliter a centimeter squared?
SPEAKER 7: A milliliter is--
SPEAKER 5: the milliliter's liquid. And it's centimeters measured.
SPEAKER 8: I'm sorry centimeter cubed.
SPEAKER 6: To get the volume.
SPEAKER 5: Oh, for the volume, right? Yeah.
SPEAKER 7: Because in the top, we have centimeters. And on the bottom, we have milliliters.
SPEAKER 5: Right.
SPEAKER 4: Centimeter cube. It's not even centimeter now.
SPEAKER 7: So does down below need to be--
SPEAKER 9: Oh, it's already cubed. So centimeter cubed is--
SPEAKER 7: Centimeter cubed down at the bottom. Yeah.
SPEAKER 4: Oh, Yes.
SPEAKER 5: So if this were centimeters cubed, then we could cross out the centimeters cubed and be left with grams?
SPEAKER 8: I think so.
JOHN ASHER JOHNSON: Yeah, one piece, though, I didn't give you is that 1 milliliter is 1 cubic centimeter.
SPEAKER 4: So we have to convert it, right? So 1 milliliter is equal to 1 cubic centimeter?
SPEAKER 6: That's right.
SPEAKER 5: So 50ml is 50 cubic centimeters.
SPEAKER 4: So technically, we have--
SPEAKER 5: That's right. Just make it centimeters cubed, then centimeters cubed up above as well? But
SPEAKER 8: But then it crosses off integers.
SPEAKER 5: Right.
SPEAKER 4: Will it really do so?
SPEAKER 8: Yeah. Now we just have grams.
SPEAKER 4: So I'm going to cut this and make it 17.
SPEAKER 5: And then we have the grams on the bottom. And we want them on top.
SPEAKER 8: And then it's 1,000, right? Because if you--
SPEAKER 4: But this is grams. It means we can--
SPEAKER 5: But the multiply now because we got rid of the cubic milliliter, the cubic centimeters, right?
SPEAKER 8: I think so.
SPEAKER 4: OK. So mass of the Earth is equal to 4 times 6667 times 667 times 66-- times 10 times 17 divided by 5. And this goes up times 200.
SPEAKER 8: Grams. Because you cross multiplied, right? And then divided by 5.
SPEAKER 4: Right.
SPEAKER 7: So then when you cross-multiply the grams [INAUDIBLE], right?

SPEAKER 4: Right.
SPEAKER 8: Yeah, OK. That's a good number.
SPEAKER 7: Are we there?
SPEAKER 4: Almost.
SPEAKER 9: For the bolt, like the steel nut and the piece of iron and the rock, they're all supposed to give similar answers.
SPEAKER 6: Oh, OK.
SPEAKER 9: There'll be a bit different, but they're all going to be kind of similar. Sorry, you had a question?
SPEAKER 7: We think we're real close.
SPEAKER 9: OK. We're excited.
SPEAKER 7: Good teamwork. Good teamwork.
SPEAKER 9: So, sorry, Patrice, I just wanted to check what are the units on what you're writing out right now?
SPEAKER 5: We think that's grams.
SPEAKER 7: We think we're in grams.
SPEAKER 9: OK.
SPEAKER 7: Because we got--
SPEAKER 8: What do you think we're in?
[LAUGHTER]
SPEAKER 9: No, I'm just not used to that. Sorry, I'm just not used to that abbreviation. For g, that's-- it's GMS standing in for grams here.
SPEAKER 5: Oh, I see. OK. So just G. got it.
SPEAKER 9: I'm used to just using G, but that's my--
SPEAKER 5: It's also cultural difference sometimes.
SPEAKER 9: I know.
[LAUGHTER]
That's what I was thinking. Like, I don't recognize your convention.
SPEAKER 5: That's all right.
SPEAKER 7: So yeah, just we were in-- we had cubic centimeters to take the place of the milliliter, right?
SPEAKER 9: Oh, I like what you wrote at the bottom, 1 milliliter equals 1 centimeter cubed.
SPEAKER 7: Yes. And then we so that got rid of the volume measurement. So now we're just in grams, we think. Does that make sense to you?
SPEAKER 9: So for the final answer of your mass of the Earth is in grams, yes. I'm a little confused by the fraction.
SPEAKER 5: OK so we looked at the ratio. We said, OK, so we'll have mass of the Earth and mass of the rock. And we put them together and tried to find out the proportion of the volume.
SPEAKER 9: I like that way of doing it. That's really nice.
SPEAKER 4: So this is all the proportion. And what we then did was we found out the volume of the Earth because the Earth is a sphere. And the volume of a sphere is 4/3 pi r cubed.
This is what we did to find out the volume of the Earth. So volume of the Earth was transferred from here to here.

SPEAKER 9: Yes, OK.
SPEAKER 5: And we divided it by the volume of the rock which is what we found out with the beaker and the experiment that we did. So it was 50 milliliters. Now, 1 milliliter is equal to 1 centimeter cube. So 50ml is equal to 50 centimeter cube. So we got 50 here. And then we just use this proportion to find out the mass of the Earth.
SPEAKER 9: Yeah, that sounds great.
SPEAKER 5: So from here--
[LAUGHTER]
SPEAKER 9: OK, sounds good.
SPEAKER 5: So now we are here in grams. So mass of the Earth--
SPEAKER 9: So you have the mass of the Earth.
SPEAKER 5: --is 16 times 667 to the power of 3 times 10 to the power of 18g.
SPEAKER 9: OK. OK. I think I understand now. Also, I really like what you did here because I think I wouldn't have thought of it that way. But the way I'm looking at this is that this relationship holds if your Earth and your rock are made out of the same thing that has that same density. Yeah. So I really like that. For your final answer, once you do out all the multiplication, I have a feeling that's going to be a little on the large side. That is my instinct at the moment.
SPEAKER 5: Do you propose a suggestion here? What should we do?
SPEAKER 9: Let's see. So all of your logic seems correct, though. So I think-- let's see.
SPEAKER 7: I wonder could we have overestimated the circumference of the Earth and therefore the radius?
SPEAKER 9: Yeah.
SPEAKER 7: That could have been an original on our early--
SPEAKER 9: So the answer that I think you were saying earlier was this. And I think this is correct.
JOHN ASHER JOHNSON: One-minute warning, guys.
SPEAKER 9: So somewhere-- I shouldn't say correct. I think it's similar enough to what I think.
SPEAKER 6: It's in the right ballpark?
SPEAKER 9: Yeah.
SPEAKER 7: Exactly. We're ballparking.
SPEAKER 9: Yeah. So then, given that, all of your logic should be fine. So yeah, I think somehow the feeling that something's gotten a little overestimated, I'm not quite sure if I'm misremembering. But all of your logic seems good. So I see no faults with the logic here.
SPEAKER 8: I don't think we had any intention of multiplying it anyways.
[LAUGHTER]
SPEAKER 7: It looks so beautiful.
[LAUGHTER]
SPEAKER 8: I'm not sure what's wrong with this.
SPEAKER 9: Yeah. I do think that if you wanted to do an estimate, then you could say something like 667 is about 500. And then--
SPEAKER 8: Oh, really?
[LAUGHTER]
SPEAKER 7: --you can estimate it.

[INTERPOSING VOICES]
SPEAKER 7: Pi is 3, right? So you could say it's about 500 and get an estimate for the final answer.
SPEAKER 5: So 5 times 5 is 25. 125 times 10, 500, right? So 100 times 3.
SPEAKER 9: Is there a reason why we're rounding down instead of rounding up?
[INTERPOSING VOICES]

SPEAKER 5: Who has their cell phone on them?
SPEAKER 6: I do.
SPEAKER 7: I want a selfie with us in front of our board. I'm proud of this work. Here we go.
SPEAKER 8: We got the first--
SPEAKER 7: Here we come.
SPEAKER 9: You want me to take a picture for you?
SPEAKER 7: Yes. We want a picture in front of our board.
SPEAKER 8: Can we take our picture?
SPEAKER 9: Yeah. Do we need a selfie?
SPEAKER 7: Here we go. Let's go cover the board.
SPEAKER 5: We have to have our board.
SPEAKER 9: All right.
SPEAKER 7: Nice teamwork, guys.
[CHEERING]
SPEAKER 6: Thank you.
KIMBERLYN LEARY: So Professor Johnson, that was a thrill to watch you and your teaching assistants working with this group. I noticed when you first began today's session, your mini lecture at the beginning, you started off not talking about astronomy, but talking about learning.
JOHN ASHER JOHNSON: Yep.
KIMBERLYN LEARY: Can you say a little bit about why that's the first approach to your students?
JOHN ASHER JOHNSON: I don't know that I've ever really consciously thought about it, but I noticed that I was doing that, too, actually. And I think it's just that over the years, I've found that I don't really need to convince my students that astronomy is worth studying and working astronomy problems is worth doing. That's why they showed up. That's why they bothered to sign up for the class.
But what I think is really important is on that first day, and then particularly in the first couple weeks, is to continually reemphasize how learning is the goal. And so I don't say it once. I say it again and again, and I say it different ways.
But to just ingrain in their minds that when you step into this room, the goal is not to demonstrate how much astronomy you know or even to demonstrate necessarily how much you've learned. But it is to just simply demonstrate learning. And so you've just got to set the tone for that because that's not typically what we do in the classroom.
KIMBERLYN LEARY: There were also some lessons in there about collaboration, about what it means to work with others in small groups. Tell us more about that. An ethic of collaboration it sounds like you were trying to get across.
JOHN ASHER JOHNSON: Yeah. A slightly not non-practical goal for me is to have fun when I'm in the classroom. And I have fun--

KIMBERLYN LEARY: That's sound good.
JOHN ASHER JOHNSON: I have fun in the classroom when there's 40, 30 something students and all talking. And the room is kind of a nice constant din. And then I know that like, D-I-N is that it's like a-- that's when learning is taking place. That's when people are having a lot of fun.
But to get to that point, we kind of need to take-- any class of 35 particularly in physics or astronomy or any of the sciences is going to have two to three of people who really did show up because they believe that they're smartest person in the room. And this is yet another opportunity to display that. We need to make sure that those people are not dominating the discussion.
And so I think that's one of the first lessons I like to give the class about what the collaboration is going to look like is that we're not trying to demonstrate to the people in the group that you're the smart one. You're trying to work with them to solve the problem. Those are completely different things.
And I find that it's like it has almost a magical effect when you just name it because everybody in that classroom has had multiple classroom experiences where that is exact thing has happened. And here's an actual professor who's naming it.
It means that it's OK to push back against it. It's OK to maybe take the discussion in a different direction if that person's in there trying to do that. And then the teaching staff milling about tries to stay attuned to that. Fortunately, this, semester I don't know that we've encountered that dynamic too much, but I definitely have had classrooms where it's been present.
KIMBERLYN LEARY: Let me ask you a little bit about the teaching staff and yourself, of course, too, the milling around. It didn't seem like people were assigned to particular groups, but they were moving from group to group. Is there a sort of master plan?
JOHN ASHER JOHNSON: There's not a master plan. It's more like the movement on a basketball court. There's kind of a zone that we're playing in the room. And so we actually did have a brief discussion that we just kind of, OK, I'll be up here. You're going to be back there.
But then as we went along, I like to know what's going on in the other rooms. And so I'll kind of tag one of the TFs out over on this group. Maybe if I had time, I could have worked over to this side of the room. Then they could bounce back over.
And they just have that variety for the groups to interact with. There's a variety of approaches. We don't all have the exact same approach, the same demeanor, the same knowledge base. And so we do like to keep things mixing around.
KIMBERLYN LEARY: Two moments I noticed with the teaching staff-- one was how some of the groups were using the teaching staff as a resource, kind of, am I going in the right direction? And getting some good feedback. And other moments when there was just frank encouragement, I think you're ready to try to solve the problem. How do you prepare your teaching staff to be that nimble?
JOHN ASHER JOHNSON: Well, I've got to get better at this. And I mean, I met with Jay and Justina, like the week before. And we just were in my office. And I turned them into students, and I became the facilitator. And we worked this exact worksheet.
And they got to be stuck, just like everyone in here. They were stuck, too. And we would go for about five minutes with me actually doing it. And then I'd pause, and we'd pull back to the meta level and say, what was just happening there? What was I doing?
And so some of the things that I highlighted more than the interpersonal touch is more-- there's actual-- over the years, I've figured out-- I don't know if anybody noticed, but we always try to keep the majority of

the students between us and the board. It's sort of a rule that I always give-- keep students between you and the board.

The moment that you change that arrangement, then students start finding a chair to sit in and prepared to get lectured. And it's just automatic. But if you continually are conscious about where you're positioning is, then you can prevent that dynamic from taking place.

Another thing that we have is a rule about minimizing the amount of time that you're touching the chalk. An ideal class session I think, for me, is when I never touch the chalk. But we do use liberal use of the eraser.

[LAUGHTER]

Because students become very tied to the amount of stuff that they put onto the board. And they start getting a little product-oriented rather than process. A good way of disabusing them of that is to just erase the whole thing--

[LAUGHTER]

--and invite them to do it again because that's where the learning is going to take place. And that was wrong anyway. You don't want to-- that's not what we're aiming for, right? And so there's mechanics that I find that are very useful.

The interpersonal part, I love it when each teaching fellow and person in the classroom has just their own way of interacting with the groups. And I learn from them as I watch them do it.

But one of the most important things is to stay very Socratic. You might have noticed that there was only a couple of things that we actually gave direct answers for. Even when we're asked a specific question, we try to stay very good at returning a question, but not in a frustrating way, but in a way that just empowers the student to get there. So those are some of the tools that we have.

KIMBERLYN LEARY: So two questions, and then we'll open it up to all of you. So you mentioned at the start this was a hard problem. And people did get stuck. I was walking around, and people were scratching their heads trying to figure it out.

But when there was a breakthrough, we noticed that we heard the joy of people solving a part of the problem.

JOHN ASHER JOHNSON: I love the proud moments.

KIMBERLYN LEARY: And then you said to me, I always step back at that moment. Can you tell us more about that?

JOHN ASHER JOHNSON: This is something I've recognized for myself is that I delight in the aha. And I want to get in the mix. I want to be a part of it. But there's not much benefit in that, other than, like, I get to work with the professor.

And so I try to-- whenever I hear the lights turning on is exactly when I start fading away because they've got it now. They're on the path. And I want them to not look to me now that they're on the path.

It's like, go, run down the path. Even if it takes you off and then you veer off in the wrong direction, run. But if I'm there, I can-- I serve more as an inhibition at that point. And so, yeah.

KIMBERLYN LEARY: So last question. It's a little more of a challenging question. So you've got small groups, and there are more active learners. There are people who pick up the chalk or the dry erase marker and are ready to go with it. And then there are others who are hanging back a little bit.

How can you make sure that that process comes to include everybody? How do you intervene with those who are off to the side? How can you be sure that they've actually taken in the lesson?

JOHN ASHER JOHNSON: There's a number of ways that I like to use-- one is just walking up to the alpha chalker at the board. And I just say, do you mind if I-- can I take the chalk for a second?
And then they hand it to me. And then I turn to another person and say, I have a question for you. I'm curious about this part right here. Do you think you could take me through it? And then I'll pick up the eraser and give them room to then step up and then do it.
Other times, I mean that's more of an extreme thing. And I don't do that as often, but it's pretty effective. But it's also a kind of disruptive to the group flow.
What we're doing at this point in the semester is we're going by the groups, and we're just taking some of the people that tend to hang back. And we just take them off to the side. And we find another board. And we just do a little impromptu quiz.
Very low stakes, there's no grade attached to it. It's just, can you demonstrate your learning? And this semester, we did this last class period, actually. It seemed like even the ones who were hanging back were pretty up to speed on everything, right? Yeah.
There's even one student in particular that I was a little bit concerned about. But I heard from Justine who ran the little-- it was like five, 10 minutes. He's just like, oh, he's solid. He's got it. And it's just like, oh that's great.
So one of the things I'm trying to help-- one of the things I'm learning the more I do this is that the person that's driving at the board, that person is not necessarily the only one learning. They're just the most visible one.
KIMBERLYN LEARY: So one of the best things in the world is to watch colleagues teach. So what a pleasure to watch you teach today. And please join me in thanking Professor Johnson.
[APPLAUSE]

JOHN ASHER JOHNSON: And I also like to make sure we acknowledge my teaching staff. I really appreciate your help today, everybody, so.
[APPLAUSE]

JOSH BOOKIN: So we now have about a little more than 20 minutes to continue the conversation with questions that are out in the audience. And these can be in the line of what Professor Leary just did, a lot of what we just saw and how that relates to the greater philosophy. But also feel free to get beyond just this lesson, and anything else that you've heard so far or read in the bio that piques your interest that you'd like to know more about as we think about disrupting traditional classroom hierarchies.
So who has a question out there? And we have some mic runners just again who will get you the mic.
SPEAKER 6: Thank you so much. This was incredibly illuminating and engaging. And I'm I suspect that when you first started to teach coming out of graduate school, this was not your approach.
And so I wanted to know if, A, is that true? And B, If you could kind of map the evolution, in brief of how did you get to using groups so intensively and stepping back so deliberately from the place of authority?
JOHN ASHER JOHNSON: No, I didn't-- this is the approach to teaching that I got from when I was an undergraduate. I was an engineering student, and I was first generation in college. And I didn't have anyone to give me any advice about how to approach college.

So I just took it as my senior year plus plus and just kept charging ahead. And I thought like I'll just take the same approach as I did in high school. It's going to be easy. And high school was fairly easy for me. But college was absolutely not.

About three semesters in, I lost my scholarship that I came in on. I had to start working a job. Engineering was a drag for me. I didn't enjoy it. I was in a crisis. I didn't know what I wanted to do.

And I took an engineering physics class by a man named Ron Bennack. And he taught a traditional lecture, but he had these he had recitation sections and office hours that were run as the Physics Learning Center, the PLC. And it was all based on this exact model right here.

Not exactly like this. I adopted a lot. But like the idea of groups at the board working where the teaching staff could see it, the teaching staff in the middle of the room. The whole positioning trick is something I learned from him. Never touching the chalk is what I learned from Professor Bennack.

And he basically caught me as I was slipping through the cracks. And he called me to his office after a lecture once. And I was really intimidated, and it was really strange because no professor had ever taken an interest in me. But he just said, I see potential in you. And these scores don't reflect that at all. What's going on?

And so he actually-- I couldn't even attend the Learning Center, because I had to work a job but he gave me an hour and a half each week in his office for personal office hours. And he basically taught me the whole process of a product, something he calls expert methodology, which we actually teach in the class here.

And so I've adopted a lot of that. And so when I got to graduate school, and I was a teaching assistant we had our own recitation sections for the intro astro course. And I just ran my 30-student intro recitation section like this. So I've always thought like this.

SPEAKER 6: That's so cool.

PATRICE: Hi, Patrice. I'm at the Teaching and Learning Lab at the School of Ed. And I was wondering how you might think of some of these techniques in the online classroom when it's fully online or in a synchronous session.

JOHN ASHER JOHNSON: Online learning is not good.

[LAUGHTER]

It's far inferior to what humans do. When you're trying to translate through the computer screen all of the nonverbal communication that takes place in the body language and facial expression and tone and the ambient environment and the energy-- the energy that you feel from the person actually right there next to you-- just, there's no replacement for it online.

And I don't believe that this is just me being curmudgeonly. I think this is just-- I gave it a go. Brian was actually one of my teaching fellows. And we kept it from being a disaster that semester when we taught online, which I think is a credit to me and my teaching staff. But it's not a way to teach. So I don't have a better answer for that.

[LAUGHTER]

Maybe I'll learn more as I go along. But, yeah.

SPEAKER: Hi. Thank you so much for the demonstration. I'm a student at the Graduate School of Education. I have a few questions. I'm curious to know what was your thinking behind forming the groups? I see that we have different alphabets.

And in the classroom which is designed with these small groups, what should be the thinking behind that? And the other is, like, how do we take students' prior knowledge into account? And how do we like-- using that, how do we scaffold the learning within these group activities? And I'm guessing this-- yeah, so when I'm asking this question, I'm thinking about adult learners, and if there's any other thing to keep in mind when designing for adult learners.

JOHN ASHER JOHNSON: As far as I know, the groups were assigned randomly because I didn't have any part in it. Was it random? OK. So they were randomly assigned. There was no forethought in the group compositions.

STUDENT: We're [INAUDIBLE] in order.

JOHN ASHER JOHNSON: OK. Yeah.

[LAUGHTER]

Yeah, the groups-- and I think the way it works for me in my class is on the first day, I invite the students to team up with the people in your immediate area in the classroom. Or if you see somebody across the room that you know, maybe use that as a nucleation site and start forming a group. And it just happens pretty organically.

After that happens, the initial groups get set up. There can be some engineering, a little bit of shuffling. But by about the third week, things tend to be pretty solidified. The groups have their own identity. They know each other really well. They're comfortable.

I've been doing a lot of active intervention inviting students to just switch groups. And we actually have a classroom agreement that if you want to switch a group at any time, there is no judgment on either from the group you leave or the group that you want to join. Everyone in the room is agreed that we have the freedom to move.

And there's been-- actually, just this last class period that we had on Friday-- yeah, on Friday, we had one of the groups that normally has four women in the group. Three of them were out, and there was only one left.

And one of the groups at the front actually just peeled off three people and sent them over. And they just filled in the group. And it was just great to watch that happen. It happened really naturally in a very friendly way and exactly the way I'd like to see it set up.

I don't really have any specific advice for how you would do this for adult learners, although this since this is my first experience with, I guess, what we would call adult learners-- most of you look like adult learners-- I think it went really well, and I didn't have to do anything different.

[LAUGHTER]

And this is also my first experience doing this particular activity with people who didn't show up inspired to study specifically astronomy. Y'all walked into this room without any particular drive to learn astronomy. And I just threw one of the hardest astronomy problems I can think of at unfamiliar people. And everybody got through about that-- well, everybody got the radius. And everybody was working on the mass. And some people had even started moving on to the moon.

That was exciting for me to see. So that was my whole experiment. And I can report that it worked well to just stick the course.

[LAUGHTER]

STUDENT: I have two questions, I guess. One is just about questions and how you encourage your students to ask questions of one another. And there's a whole art to asking questions. And I'm wondering if you ever pull back the curtain at all and say, hey, let's talk about questions sort of similarly to the way you did with us at the beginning if you sort of help them along?

And then the second piece is sort of about your colleagues. I know nothing about science. But are you an outlier in the science department? Or are you are you like the norm in the Science Department?

I mean, I'm just sort of curious. Because if I had encountered someone like you in my undergraduate years, maybe I would have taken a science course. And I'm just sort of curious where you fall and how your colleagues respond to your teaching to the extent you can say.

JOHN ASHER JOHNSON: I'm definitely an outlier. At my first stop, the institution where I was as an assistant professor my first four years. I was actually pulled aside and had a talking to from the department chair on a couple of occasions about how as a young professor working on tenure, I need to be demonstrating my expertise in the classroom. And that was very important for my eventual tenure case and now that I'm being observed in the room.

And I shrugged it off. I didn't care. What is that? What's the value in that? And I also just figured if that was their actual, approach then teaching wasn't going to weigh very heavily in the tenure decision.

[LAUGHTER]

So I was an outlier there. I'm an outlier here. Actually, I was just talking with Brian on the way here, and I asked him about how many of your classes have used sort of a flipped approach?

And he was just like-- was there any? Were there any other? One? One or two? Yeah, and Brian is completing his astrophysics major right now and probably also with physics.

And so in the department, there has been some adoption. The companion course to 16 is astro 17, which is extragalactic astronomy. And I know that the instructor there has moved it sort of to a two thirds lecture, one third group work. And that's great. I think that movement is nice to see.

But I've never had a classroom observer in my time here at Harvard, 10 years. I don't know if this method is widely known outside of Hilt and now here. And I think that it just sort of reflective of the fact that the theme here is disrupting hierarchies.

But my view and what I've learned in my time as a professor is that dominance hierarchy is the structure of our entire society, and Harvard is a reflection of that. And Harvard is not some place that's trying to-- as an institution, it doesn't benefit its own survival by challenging that directly, despite the existence of today.

And so the classroom structure that you encounter actually reinforces that dominance hierarchy by teaching students to look outside themselves for things like affirmation, even assessment of their own learning, their own value, what to value, how to interact with other people. All of that instruction-- the way that the traditional classroom is set up is that all of that exists outside of them.

And what I'm trying to do with a lot of what I'm doing is to bring it more internal to them. I want to empower them to assess whether or not this is a good education-- whether they are receiving a good education, whether they are learning, whether they are studying the things that they like to.

And so I like to hand agency to the students. Particularly, in my 100 level classes, I give them a lot of agency on where do we go next? So I taught exoplanets. And we had four different check-in points where the students decided what topics we're going to do next.

And I'm trying to give them a sense of their own power. But the traditional classroom model sort of externalizes that. And that, in turn, just reinforces the hierarchical system that they're all being trained to go out and participate in. And this is the site of that training.

And so I'm not entirely surprised that this hasn't spread campus-wide because I think that students campus-wide are empowered in this sort of model start feeling their oats for other things and start making other demands. And those types of things just are truly disruptive to this institution and potentially to larger society.

So that's my little-- thanks for asking me that question so I can get my little soapbox in there. I appreciate that.

STUDENT: Then my second question was about questions.

JOHN ASHER JOHNSON: Oh, about the questions. Yeah. The best way to do that for me-- in my experience, I don't pull back the curtain necessarily on asking questions. I think there's probably some value in that, actually, now that you're mentioning it.

But the way that we tend to do it is just model them. Most of what we're doing is not feeding information. We are asking them questions. And so when I go to a board, I like to say, can you please explain this to me?

And I can judge the explanation. And if it's a little bit, I'll say, ah, I feel a little shaky. I don't quite-- I don't I don't even know exactly what to ask. But the point where you started talking about the radius and volume, I was a little bit fuzzy.

And they're like, oh, OK, right. And then I'll turn to maybe somebody in the back and just like, do you want to step in? And they're like, yeah, yeah, yeah, yeah. Actually, it's just the volume is actually related directly to the radius cubed. And I'm like, oh, wow, thank you. And so just by actually modeling and showing them.

And another thing that we do is I like to make mistakes at the board. And then I'll just stop and I'll recognize that I made a mistake. Sometimes I actually make a mistake. Sometimes I'm faking the mistake.

But I'll stand back and just be like, I don't think that looks right. Does anybody understand what's going on here? And then there'll be a little bit of murmuring. And then I'll just say, actually, I need everybody to talk to your neighbor and figure out what I just did wrong here. And I'll just walk off the stage, and I walk to the back of the room.

And then the whole room starts erupting in discussion. And then I come back up. And it'll actually sometimes will give me time to figure out what it is that I actually did.

[LAUGHTER]

And then I'll come back up. And then I'll start calling, and I'll get all this interaction, all of these questions, all of these comments. And so it's just by showing them that it's OK is the best way to do it. I think we had a question over here next in then back there.

JAN: Thank you. My name is Jan. And thank you for the teaching today. I actually was surprised how engaged I was in the exercise. And I have two questions. First one is my reflection of what happened. And I wanted to see if that was intentional of you as a teaching is that I noticed that after you came, the teaching fellow came several times, asked the same question of following the process.

And I'm the kind of person who stays in the back. And I was like, the more-- the same question you came to ask, like different people went around to explain. And so I was listening the different version of the same process. And I was learning. I was understanding it. So I wondered that was an intentional way of as a teaching team to make more than one round to just ask the question and inviting different people to explain for someone like me to really learn by repeated explanation of the process?

JOHN ASHER JOHNSON: Yeah, something that happened this semester already was I noticed that one of the groups in the back of our room, I sensed that they were a little bit intimidated when I would come up and ask them questions. And so the voices got a little shakier, and just things in the body language.

And so I think it was-- I might have been- was it you that I sent you into the back corner? And I was just like, Justina, actually, would you mind going and spending some time with that group?

Because I was like-- I think they felt like I was really hammering them because there was just one concept. And I was really wanting them to explain it in a way. I wasn't quite hearing the right explanation for it.

And then after I got in there, I was just like, uh, I think I'm hammering this group. I need to back away. And so that was one very intentional time that I can think of.

But just, I think we have a-- I don't know. I feel like we have a good flow in the classroom. And it's really great to hear that was happening in here, too, because it's a very unfamiliar setting. And it was really encouraging to hear that it was helpful for you to have that same question asked.

Because I think what's happening in that case is not that we're planning to ask that same question. It's just that same point at the board is noticeable to all of us. We've all done this problem. We've all helped dozens of students through it.

So when we go up to the board-- and that's something that's really key to this whole thing I want to mention is that we didn't allow you to stay at your table writing on pieces of paper because if you're down on the table on your iPad or on a piece of paper, we can maybe peek over your shoulder, but we're not getting a sense of what the group is doing at that point. Now we're getting really myopic.

But if you have it on the board, I can sit here and see where this group left off. I've seen it enough. And my teaching team can do that, too. And so we're probably all keying off the same thing on your board is what's happening there.

STUDENT: Thank you. And if I can ask my second question, I really appreciate how you talked about the speed of learning and that it was-- I actually even wrote down like it's about the process, not the product. But when I talk to my students, no matter how much I try to convince that, at the end, it's like, so about the grade, right?

Especially first gen students are especially worried because very tied to their job. I feel like I don't want to generalize all first gen, but I feel like, at least in my students, their pressure is higher. That they need to do well. So how do you grade?

JOHN ASHER JOHNSON: I have a specific mini lecture for that right there which I have delivered this semester. And it's about the belief system in academia that the distribution of grades-- actually, let's make that F and then A-- that we should have something that looks like this.

This is what's called a normal distribution. And we use this in science quite often. It's associated with random processes. And I don't believe that learning should be random.

And in fact, if this is the actual outcome of most learning at this institution, that's an indictment, right? That's not a good outcome. And so there's this other form of a distribution that we use in astronomy and physics and in the sciences, and it's called the dirac delta function.

[LAUGHTER]

And it's a really unique function that just says that all of the probability density exists at one point, right? And so this is what I think should be the outcome of good education and effective learning. And so the course is set up in such a way that I believe if students show up every single day, and they participate enthusiastically and in good faith with the worksheet activity, and they also ask questions and interact during the lecture material, then that is a strong indication that this is being manifest.

And so this is my expected distribution for this class this semester. And so deviations from this-- you can talk to me if you would like to get something other than this. And we can come up with that agreement. But I'm going to assume that everybody is also aiming for this distribution, so let's work together on this. So that's one way that I can do that is to remove the idea that there's a scarcity of A's. That scarcity mindset is really damaging to learning. The idea that you have to compete against your fellow learners to get one of these and to make sure that they don't is normalized. And it's going to be repeated throughout their earning careers as they go out into the world, but it's not effective for actually learning astrophysics. And so it's just messages like this. I just straight up tell them that I am bored to death of grading. And if I could get away with never grading another thing again, I'd be a very happy professor.

Like, these little things just genuinely communicate to them that I don't care about grades is something that-- I don't know if it's that I communicated effectively or if I just do it enough or if I do it sincerely. I think that's probably the key is I do it sincerely. That they kind of start colluding with me, right?

And they just show up, have a great time in class, demonstrate their learning, be excited about showing how much that they've-- how much learning that has taken place. And then at the end of the semester, this is what ends up happening at Harvard anyway, right?

[LAUGHTER]

So it's not like I'm getting away with much of anything. So I just de-emphasized the grade part, and I continually emphasize the process part.

JOSH BOOKIN: So I hate to be the one to step in, but that is my role today, and say that we are at 4:30. We had a vector joke that was appreciated by a math professor. So we've covered many of our bases.

[LAUGHTER]

But I just want to, one more time, thank you to Professor Johnson--

[APPLAUSE]

--to his teaching team, to Professor Leary.

[MUSIC PLAYING]

Thank you to all of you for coming and showing early-day energy late in the day.

[MUSIC PLAYING]