[MUSIC PLAYING]

ANNE WHITE: We're hurtling through space on our planet, and we're just bombarded by high-energy particles from the universe all the time.

SARAH HANSEN: Today, on *Chalk Radio,* we're delving into the fascinating world of nuclear physics. I'm Sarah Hansen. For this episode, I sat down with Professor Anne White, physicist and professor in the Department of Nuclear Science and Engineering at MIT.

ANNE WHITE: My research is on fusion energy, so I'm a plasma physicist hiding out in an engineering department.

SARAH HANSEN: I so enjoyed this conversation with Anne. The information she shared in this interview changed the way I experienced the air around me. I mean, how often can you say that?

The topics that she explains are complex, but she makes them so approachable, even showing us that we can learn about nuclear science using objects that we find in our own kitchens. So for this episode, we're going to do something a little differently from what we've done previously and air this interview in its near entirety. We talk about the importance of play, puzzles, and even LEGOs in Anne's journey to becoming a physicist, how certain mentors propelled her along the way, why she adores fusion, and how she came up with the cloud chamber, a hands-on tool for helping students visualize background radiation. It's a little longer than our usual episodes, and I think you're going to love it. So without further ado, here's my conversation with Professor Anne White.

How did you become interested in physics? Like, how did you go from when you were a little girl, to becoming a physicist now? How did that start for you?

ANNE WHITE: I think I always enjoyed building things, whether it was LEGOs, which I have very fond memories of. I always enjoyed doing puzzles, so lots of just jigsaw puzzles. And my hobby as a child, young adult, and now, old adult was always reading. And so I just loved reading, and problem-solving, and learning, and building. And I got really interested in math and physics. And it was really hard for me. I wasn't good at math.

SARAH HANSEN: Oh, really?

ANNE WHITE: I remember struggling tremendously in seventh and eighth grade in the United States. So I don't know, is that middle school? No, that's junior high school in the United States. I struggled a lot with it. And I was unhappy that I was struggling. But I took comfort in the fact that I could get better by practicing it.

And it was a lot like learning another language. The more I tried to speak it and made mistakes, the more I would learn. And I was fortunate that I had teachers who were really supportive and there to help, and parents who were really supportive and there to help who never said anything to me, like, you're struggling because you're a girl.

They said you're struggling because math is really hard. And that reframed it for me. And so I didn't at the time how important that kind of support was for learning how to do science, but I see it now.

SARAH HANSEN: Yeah. And it carries right through. The reason you loved this to begin with was the building, and the play, and the LEGOs and the puzzles, you can see how that would carry right through to hands-on physics and chemistry. And that's going to tie-in to what we're going to talk about today, which is making nuclear science, of all things, hands-on, which seems so improbable, right?

ANNE WHITE: Absolutely. I sometimes say it's a goal to expose a lot of people to radiation. And that sounds terrible.

SARAH HANSEN: It does.

ANNE WHITE: But it's to expose them to knowledge about radiation, and what it is, and why we should think about it in certain ways, and why we should sometimes be quite worried about it, and other times, not be worried about it. And so there's a real interesting conversation that can happen once we start learning about something which is very frightening in many ways.

SARAH HANSEN: Yeah. I'm curious, from my perspective, as a woman in physics, did you experience any challenges in the field to becoming your academic self and advancing your career?

ANNE WHITE: I think that isolation is one thing. When you're an undergraduate in physics, it's about 50% men and women. so to speak. And of course, non-binary individuals and gender plus individuals as well. But predominantly, if we talk about a breakdown between people who identify as men and women, it's about 50/50 as an undergraduate.

But when you start getting into graduate school, the numbers of women in your classes drop. And so, in graduate school, for many years, I was the only woman in any of my classes. And I was the only woman in my research group. And I was the first woman to ever work in the laboratory that I worked at.

So isolation, I think, is one thing. And certainly, looking back, I thankfully never experienced the kind of, shall we say, very negative experiences that a lot of women have that the National Academies Report talks about in terms of gender discrimination, and gender bias, and sexism, or overt sexual harassment. And so understanding those experiences and learning from that, learning how to be supportive of other women is really important, and learning how to try and change conversations.

I would be at lunch with other graduate students in the physics department where I went to grad school, and they're all men, right? And one of them would say, you're only in grad school because you're a woman, and they needed-- they needed to meet a quota of women. Or other times where I remember people saying, women just aren't as good as men at physics and math.

And I remember saying to this fellow, that's ridiculous, because I'm doing better than you in all the courses. I'm writing papers from my research, and I'm going to graduate before you. So tell me again. And so, unfortunately, that still happens.

SARAH HANSEN: Yeah. So I guess the flip side of my question is, were there any experiences or mentors that really propelled you as a woman in science to reach your highest potential?

ANNE WHITE: I would say it was probably two particular mentors when I was an undergraduate where I look back and say, wow, those experiences really mattered. So I would say I've had a lot of mentors, and more importantly, I've had advocates. And for the most part, they've been men. I will say that.

And that's perfectly all right. However, representation does matter, and so I was very fortunate to have a wonderful woman professor. So having representation and role models is one thing, but there really are two mentors who stand out and conversations with those mentors that I think really mattered.

It was the mentor in the math department, because I was a dual major in math and physics, and I asked him one day, hey, do you think I've got what it takes to go to grad school? And without missing a beat, he said, yes. And that really mattered. There was no pause. There was no questioning.

There was no hedging. Well, maybe, if it's this school or that school. He just said yes. Sort of, like why are you even asking? Of course. Go and write your-- go and finish your application. So that really mattered.

And then, I was a math major, and the other conversation that really mattered was with the professor who would become my advisor as a physics major. Because I talked to him at a Society for Physics Students meeting, and SPS meeting, and he said, I know you. You're in all the courses. Why aren't you a physics major?

And I said, well, I'm not a physics major because, in my freshman year, I talked to my physics advisor, and he said, well, your grades aren't that good, and it's just going to get harder. I think you should major in something else. So I did. I majored in math. And along the way, I took all the physics classes I liked, ignoring any kind of track because I wasn't a physics major.

And the look on the face of the-- he was the department head at the time-- when I told him this story was just-- it was this look of maybe anger, maybe disappointment. And he said, be a physics major. I'll be your advisor. And he did.

So I declared physics as a dual major and finished up the courses. And so those two conversations were, looking back, really impactful. Because it was about validation. It was about people not saying you can't or you shouldn't. It was people saying you can and you should.

And that really mattered. And I try to remember that. And I've gotten to have one of those conversations where a student asked me, should I go to grad school, and I said yes without missing a beat. It was like that moment, I said, yes, absolutely. And let's talk more about it, but the answer is yes.

SARAH HANSEN: It gives me chills.

ANNE WHITE: I felt really happy in that moment.

SARAH HANSEN: Wow. To be able to give that moment to someone else, that validation. And you don't know how you propelled that person's career, and what difference to science you might have made for all of us really by encouraging that person.

ANNE WHITE: Well, she's done amazing things, but had nothing to do with me. I'll just say that.

SARAH HANSEN: Wow. Let's talk about another amazing thing, which is fusion energy. I know this is close to your heart. Could you explain to our listeners and to me what it is, and in what ways it might be a transformative energy source, and why that matters?

ANNE WHITE: Absolutely. So you look up in the sky and you see our sun during the day. You look up into the night sky and you see so many stars. Each one of them is powered by fusion reactions.

So deep inside the core of the stars, the lightest elements in the universe, hydrogen, are brought together in nuclear reactions. They're fused together to produce helium. And in stars, that cycle continues up with lighter and lighter elements being brought together in fusion reactions to form heavier elements, all the way up to iron.

And so that's really how fusion works in stars. And the star is a big burning ball of gas. And that has a more technical term, which is plasma.

So a plasma is an ionized gas. It's the fourth state of matter. If we start with a solid and we add some energy, we add some heat, we can melt it, and we can create a liquid. And we take that liquid, we add more energy, we add more heat, and we can turn it into a gas.

And if we take that gas and, again, add more energy or heat, we can ionize it. So we can give the particles so much energy that they're no longer neutral, that we can strip the electrons away from the nucleus of the atom, and now, we have positively charged ions and negatively charged electrons swirling around in this ionized gas. That's a plasma.

And fusion plasmas in stars are held together at very high densities for hundreds of millions of years by gravity. That's how the plasmas in the stars is confined. And that's how you're creating confinement for so many fusion reactions to occur and release that nuclear energy by e equals mc squared.

And so, how do we do that on Earth? We're trying to bring a star to Earth. And you can't really put a star-sized chunk of matter on Earth. That would be a bad idea for a lot of reasons.

And so, instead, what we do is we take plasmas, and we want to put them in an appropriate container and heat them up to very high temperatures in laboratories and confine them in order to have enough fusion reactions happening so that we would be able to get more energy out than we put in. And the main ways we can find them in the laboratory for a fusion energy system to produce a lot of this very clean, very abundant nuclear energy on Earth through fusion reactions is holding them with magnetic fields. That works well.

We can also compress them with lasers. Basically, squish them together for a short period of time. So those are the primary ways we do it, magnetic confinement or inertial confinement.

SARAH HANSEN: OK. You hear nuclear energy, and you think, oh, danger. In what ways is this safe?

ANNE WHITE: Well, I would definitely want to come back to that first feeling of danger when we think about nuclear and talk a little bit about fission energy, if that's OK, and fission power plants. So I think, in the media and in popular culture, fission gets a bad name. But if you look at the data-- and it's a bit of a morbid statistic, but if you look at the data and say, well, how many deaths per kilowatt hour of electricity produced by power source, can you guess what the safest one is?

SARAH HANSEN: No.

ANNE WHITE: Do you have a favorite power source or electricity source?

SARAH HANSEN: Let's say, like, turning on a light, like that.

ANNE WHITE: Sure. Sure.

SARAH HANSEN: Let's say solar power.

ANNE WHITE: Solar power plant, let's say, might be your favorite. I love solar power.

SARAH HANSEN: It has a very good reputation.

ANNE WHITE: Absolutely. And it's the safest. It feels like that.

SARAH HANSEN: Why do I have a feeling you're going to tell me I'm wrong?

ANNE WHITE: No, you're right. It is the safest. That's what the data show us. And can you guess what the-- let's say, what's the most dangerous. Can you guess what the most dangerous?

SARAH HANSEN: I'm going to guess it's like, nuclear energy.

ANNE WHITE: It's actually coal. It's actually coal. Coal is the most dangerous. When we burn coal, it produces a lot of really problematic pollution, and millions and millions of people die around the world all the time from air pollution. It's really, really sad. So we definitely want to get rid of that kind of danger for humans.

And of course, we haven't even touched on carbon emissions and climate change. So there you go. There's the safest, solar, and there's the least safe by that statistic of deaths per kilowatt hour, coal. What do you think the second safest is?

SARAH HANSEN: Like, hydropower? Wind power?

ANNE WHITE: Nuclear.

SARAH HANSEN: Wow.

ANNE WHITE: Nuclear is on par in terms of safety with solar and wind.

SARAH HANSEN: Really?

ANNE WHITE: Yes. Absolutely. This is because fission power plants are engineered to be that way. Many researchers and scientists and behavioral psychologists can tell you many more detailed things about their scholarship and their research on this, but not being an expert, but just being a human, I would say, absolutely. We're scared of the big scary things. And we remember the big scary things more than other things.

If we were out in hunter-gatherer society, we would remember that down that canyon, our buddy got eaten by a lion. That's probably more important than remembering all the other canyons that were safe. We remember that one really, really scary canyon. So I think it's natural that we have different ways of assessing risk or thinking about risk.

And also, there are some really scary things about nuclear. I mean, we have to be very realistic about that. Yes, it's a clean form of energy that can be well-managed, and it's extraordinarily safe, et cetera, et cetera, but it was born out of a weapons program. It was born out of some of the worst things humans have ever done. And that's a legacy that will continue.

And there's also a sad history and legacy of the lack of transparency around nuclear, and not engaging with communities, and not getting buy-in for the siting of a power plant, or the siting of a waste plant. And I think that we need to reckon with that past and do a better job at thinking about how nuclear can be part of a sustainable and an equitable future. And those are challenging conversations.

And we need industry leaders, we need higher education leaders, we need community leaders to bring people to the table and to have those conversations. But it's hard. I mean, you get an entrenched opinion, you feel very strongly about it. Movies don't help us.

And as much as I might want to try and tell people something about nuclear that could, not change their mind, but get them to open their mind and be open to learning different things about it, that's never going to compete with hundreds and hundreds of millions of dollars to make a really extraordinarily provocative series on TV, or in the movies, and star power. We can't compete with that. Fission is the best chance we have at rapidly enabling people in all parts of the world to have access to electricity, clean water, safe food to eat, without putting carbon into the atmosphere.

So I'll just start by giving that plug for us to all rethink about nuclear power and rethink about fission. But there really are trade-offs with anything. We don't get, ever, something for nothing. And so with all sources of energy, we have to also think about waste. We talked about safety, but let's talk about waste and the impact we have on the environment.

We are going to mine an awful lot of materials in order to build out solar and wind. And mining has a very detrimental effect on the environment, mining for uranium for fission energy as well. So that's a very real impact that we have to think about.

We don't currently have a way of managing the waste from our solar cells. That's another very serious thing that we have to think about as a society. Because it is a problem. The chemicals can leach into groundwater. We have to be very careful with how we contain that kind of e-waste. And there's a lot of projections for what that looks like.

If we think about nuclear waste, as one of my colleagues will tell you, it's actually one of the best managed wastes we have. And we've learned a lot about waste management from it. This is, of course, because a legacy of having to manage waste from weapons productions in the 1940s and '50s.

But when it comes to civilian nuclear power, and the United States is a good example, we've been using nuclear fission power for 60 some years to produce carbon-free electricity in the United States. And if you took all of the high-level waste, the stuff that we're really worried about we do not want people or animals in the environment to come in contact with that, we want to isolate it safely away from everyone. So you take that high-level waste that we've produced from 60 years of civilian nuclear power generation in the United States, you could stack it all up in one football field. One football field. And it wouldn't be stacked very high.

That's because the energy density of fission fuel is so very high, and the fuel is still a solid piece of rock. But much more radioactive. And the waste is also, therefore, a solid piece of rock, but radioactive. So we're not making a lot of it.

And if your viewers are familiar with drinking soda from a can-- I won't name any brand names because they don't want to be affiliated with a conversation about nuclear waste-- but hold that soda can in your hand. All the high level waste generated to produce all the energy in your lifetime can be stored in a volume the size of that soda can. So, yes, the high-level waste from nuclear civilian power plants is very radioactive. It must be kept away from us. It's dangerous. We don't want to interact with it. But it's entirely manageable.

And multiple countries are showing us, in Sweden and Finland, how high-level nuclear waste from clean, carbon-free electricity generation and power generation can be safely stored in underground repositories. With the right kind of geological investigation and engineering investigation, it's entirely possible to manage that waste. And so I think it's important that we always keep that in mind. Only after saying that can I then compare it to fusion and say, fusion is even better.

SARAH HANSEN: Oh, wow.

ANNE WHITE: And the reason for that is the energy density of the fuel. The more energy you get from fuel, the less waste you will have. So if I want to power the city of Boston with coal, which I do not want to do, I would be filling up Fenway Park with coal every year to power the city of Boston. If I wanted to power the city of Boston with fusion fuel, deuterium and tritium sourced from water and rocks, I would need a pickup truck bed full of fusion fuel for the entire year of the city of Boston.

SARAH HANSEN: Wow.

ANNE WHITE: And I'm also not producing any carbon emissions from burning that fusion fuel in my fusion energy system. I'm not producing any high-level waste. The waste that is produced is very similar to medical waste or research waste in terms of having some radioactivity associated with it. And it's ultimately very clean. Because, again, no carbon emissions, no particulate emissions.

SARAH HANSEN: My goodness. It's just mind opening. Let's talk about the cloud chamber.

ANNE WHITE: Cloud chamber. Yes.

SARAH HANSEN: The cloud chamber. So you've developed a diffusion cloud chamber to help students-- and correct me if I'm wrong-- but visualize background radiation. Can you tell us in your own words what a cloud chamber is?

ANNE WHITE: Absolutely. So a cloud chamber, if you can visualize it, is a container. It's a jar. So no harm thinking about an empty jar of tomato sauce or spaghetti sauce that you may be using to cook your dinner. Let's start with that.

It's an empty jar. And inside this empty jar, you've somehow created what we call a supersaturated vapor, maybe of alcohol or water vapor, somehow. Maybe you've created this by really cooling it down a lot compared to room temperature. And once you've got this super saturated vapor, it acts the way a lot of supersaturated water vapors or liquid vapors act.

If a tiny piece of dust settles into it, or an ion settles into that supersaturated vapor, it creates a nucleation site and clouds form. It's the same way clouds form up in the atmosphere. So that's why it's called a cloud chamber. Because when these little nucleation sites become activated, you'll see a little wisp forming inside the jar that you're holding in your hand, and that's this little cloud.

SARAH HANSEN: That's so interesting. And why did you want to build this?

ANNE WHITE: So I wanted to build it because I always wanted to build one growing up, but I never had access to dry ice. I remember, maybe, probably, and if my parents hear this, they might say, that's not how it happened, but I remember asking, can we go get dry ice and make a cloud chamber? And my parents were like, I don't know how we can get dry ice. Nobody knows how to get dry ice.

I did grow up in a desert. Maybe that's part of it. But it was something I always wanted to do. And for a long time, at MIT, in our classes, we've always thought a lot about, how can we make nuclear education more hands-on? How can we really have different conversations about radiation?

I mean, most of the time, when you teach about radiation at the undergraduate level or the high school level, the instructor or the teacher needs to have a radiation source. You can buy these from plenty of educational places. I've bought a bunch of them. They deliver them right to your house.

But you might not want to do that. That's a barrier for some people. And it's also, I think, important to try and understand what background radiation is. So this idea for a cloud chamber really came from this desire to, one, have a different conversation about radiation with my students in a very hands-on way and have them experience it for themselves.

It came also from a desire to talk about background radiation and make that more of the conversation in the classroom. And the third thing was it came from a desire to really empower students and build their confidence. Because cloud chambers are really widely used in education, and they tend to be used as a demonstration. The instructor, the teacher will set it up, and people will come in and watch it do its thing.

And it's very passive. It's beautiful. It's interesting. And you accomplish the goal of visualizing radiation. As a charged particle passes through that supersaturated vapor, it creates a track, a little line of cloud that you can watch, and, wow, that's amazing. That was a charged particle.

Yes. That's true. It's great. But if you wanted a student to build a cloud chamber on their own, you probably would need to do this over several course sessions. You would need lab materials. It's a big investment.

And so what I wanted to do was create a kit that would let any instructor, high school or college level, insert a cloud chamber building project into their classroom. And it can be done in one 50, 5-0, minute lecture. And it's designed so that students build it once through, and probably fail to get it to work.

They don't see any tracks. They don't get it to the supersaturated state. But there's enough time for them to take it apart and build it again based on what they learned and based on what they did wrong and figure out how to get it right on their own, all in one single sitting.

So you can have a conversation about background radiation. You can have a conversation about trying something, making a guess about why it didn't work, and then trying to fix it and make it work, and then, also, actually visualizing background radiation around you. So combining a lot of pieces of experiential learning, hands-on learning with this mysterious radiation that's all around us.

SARAH HANSEN: And now, I have a question. You're going to be like, wow, I can't believe she's asking that.

ANNE WHITE: Never.

SARAH HANSEN: This is definitely not going in there. So you create the environment inside the jar, and you're really measuring the atmosphere trapped inside the jar? Like, they can't pass through the plastic barrier?

ANNE WHITE: Oh, they absolutely do. They're so high energy, they're passing through your body right now.

SARAH HANSEN: Really?

ANNE WHITE: Yep. They're passing through this building. We've just been bombarded by muons. There goes another one. And another one. And another one.

SARAH HANSEN: So it's really like, what is around, and it's not like, what you're trapping in there?

ANNE WHITE: No. No. These are coming from-- these are coming from supernova millions and millions of light years away. These are high-energy particles going all through the universe, passing through our Earth all the time.

SARAH HANSEN: Just like, right through you?

ANNE WHITE: Yeah, right through your body right now we're sitting here. And if we had cloud chambers in here, we'd be seeing little streaks and little tracks.

SARAH HANSEN: Wow, OK.

ANNE WHITE: Absolutely. It's all around us all the time. If you were to place a radioactive source inside a cloud chamber-- you can Google videos of this. People have it. It's really amazing. Because you see just rays of the clouds emanating from the radioactive source because it's emitting radioactive particles.

But when you don't have the source, and the cloud chamber's just sitting there detecting background radiation, they come from all directions. Because we're hurtling through space on our planet, and we're just bombarded by high-energy particles from the universe all the time.

SARAH HANSEN: Wow. That's so interesting. I'm glad I asked that question. There is no such thing as a dumb question.

ANNE WHITE: No. But you might asked, should I be worried about cosmic rays?

SARAH HANSEN: Yeah. Well, I'm worried about everything, so I'm assuming yes.

ANNE WHITE: No. The Earth is shielded by our magnetic field. The Earth is shielded by a magnetic field, and it makes the charged particles bounce from the North Pole to the South Pole. So we have two gigantic donut-shaped belts that are populated by energetic electrons and protons. So you'd have to go up into the atmosphere, out of the atmosphere, to actually really need to worry about cosmic rays.

Like, astronauts should worry about them. And we do worry about radiation shielding for astronauts, et cetera. And that's because the Earth is shielded by our magnetic field. The magnetosphere also deflects cosmic rays and protects us from solar flares.

So we're very fortunate that we live on our planet and our planet is the way it is. But of course, cosmic radiation does reach us. But it doesn't cause any harm. It's there, just like all the other low levels of radiation that we are regularly exposed to.

SARAH HANSEN: I have so many follow-up questions. The first one is, how does having hands-on experiences with background radiation allow you to have different kinds of conversations with students than if they were to just see it?

ANNE WHITE: Well, I think you make a fair point, which is maybe I was squishing too much into the pedagogy. So maybe you can have exactly the same conversation just by looking at it. But the other cool thing about it is they could take the kit home with them. And then, they could repeat it in a different location and maybe see differences in the background radiation.

So a lot of it is about just lighting a spark inside them to be a little more creative. Rather than have it be distant from them as something someone else built that they get to see it's something they built. So I think that's just maybe germane to education and not specific to radiation education.

SARAH HANSEN: Yeah. And so I'm looking at the cloud chamber now, or parts of it, and it really is. It's a jar and a sponge.

ANNE WHITE: Oh, yeah.

SARAH HANSEN: So you would saturate the sponge in rubbing alcohol, correct?

ANNE WHITE: Yeah.

SARAH HANSEN: And then, you cover the inside of the lid with black paper.

ANNE WHITE: Just to have a good background for contrast.

SARAH HANSEN: OK. And then you turn it upside down.

ANNE WHITE: Yeah.

SARAH HANSEN: The sponge goes at the bottom and then you turn it upside down.

ANNE WHITE: Sponge at the top. Yeah. So you take the jar-- I'm right-handed, so I'm going to hold the jar in my left hand. So it is a small plastic jar and I'm holding it in my left hand. So I would take the sponge that I got from under my kitchen sink this morning before coming to join you here today and I would soak it in some alcohol.

And that's part of the experiment. Figure out how much rubbing alcohol you need. Does 70% work? Does 90% work better? There's a lot of experiments you can try.

So I soak it, and it's not dripping wet, but it's wet, and I stuff it in there. And it just sticks by tension up in the top of the jar. So that's another beauty of this kit. I don't need any tools.

Then I take this little screw top and I cover the inside of it with black construction paper. So I cut out a little circle. So I guess, technically, I use a scissors, but you could tear it with your hands if you wanted to go down the whole no tool thing. And then, maybe you can hear this. I'm going to screw it on.

There we go. Make sure it's nice and tight. And then, I set it with the metal lid down on top of some dry ice and wait for about five minutes. And the little cloud chamber, this jar, will prime. And what you'll start to see, if you look through-- this is a plastic jar, so it's clear, you look through the side, you'll start to see this fine mist sort of falling down from the sponge.

And it's primed at that point. That's great. That takes a few minutes. And then, you just wait. And then, you'll start to see muons, electrons, protons, alpha particles just coming from the background around us. So cosmic radiation, you'll see muons streaming through there, very nice, thin streak of cloud, a very straight line in your cloud chamber.

You might see an electron which might take a little bit of a bendy path because it's lower energy. It might bounce around a lot, have a couple of collisions. Or you might see a puff, which is an alpha particle which is coming not from cosmic radiation, not from the universe, but from the rocks all around us. So in New England, there's a lot of granite, so we tend to have quite a bit of that type of radiation as well. And it works for maybe about 5 to 10 minutes in one sitting before you need to open it up, reset, and get your sponge wet again with the rubbing alcohol, and do it all over again.

SARAH HANSEN: Yeah. It's incredible. I mean, it feels like this kind of kit that you've developed, it makes science belong to everyone. Like, a kindergarten teacher could do this with kindergarten students.

ANNE WHITE: Yes. And I have done. So before I deployed it in my classroom at MIT, it had to be tested. And the most difficult test was with a group of three, four, and five-year-olds.

SARAH HANSEN: Yes. They are a tough audience.

ANNE WHITE: They're a tough audience.

SARAH HANSEN: And super smart.

ANNE WHITE: And they're super smart. But we got it to work with them. So that was a lot of fun. Their parents helped us. Another tough audience was, I would say, adult learners. So I managed to get together a bunch of folks here at MIT who are not professors and not scientists, but our wonderful staff and administrators in the department.

They were kind enough to volunteer and let me run through the whole thing with them to practice on, and they got it to work. And so I said, this is great. If kindergartners can do it, and people with not a science and engineering background can do it, then certainly, a freshman who's taking a undergraduate engineering class at MIT should be able to do it. And sure enough, we ran it with 20 students in the classroom, paired them up, and in the one hour, after two rounds, everybody got their cloud chamber to work.

And the other reason I really like it is there was no prep work for me that day as the instructor. I just brought the kits to class and let the students build them. Which is also key. Because if we want this to be something high school teachers can use or middle school teachers can use, they're not going to have time outside of class to go and build some beautiful demonstration cloud chamber. They wouldn't have funding to do it.

These kits, we published the list of what you need to buy from Amazon. They're very inexpensive kits. And really, can build them with things you have in your kitchen. I joke it's a kitchen cloud chamber.

So it was really also meant to lower that type of barrier. The one barrier I wish I could remove was the dry ice. Because that is still hard, I think, for a lot of instructors to get their hands on.

SARAH HANSEN: So what was the reaction of students? What was the impact on their learning that you could observe?

ANNE WHITE: Maybe the most exciting thing for an instructor is silence when they were just watching their cloud chambers, and then, excitement, and then, sharing. Come look at ours. Come look at this one. Oh, I got this on video. Look, I took a picture.

It was really fun. Because they all had smartphones and they were all pulling them out and taking the video and taking the pictures. And so they really enjoyed it. It was a lot of fun. And it was what we did the very first day of class, to just get everybody excited about the concept of-- none of them had ever built a cloud chamber before.

Some of them knew what they were, because, again, they're not an uncommon educational tool in science classrooms in this country. But none of them ever built one before. And so it was about coming into something where a lot of them didn't know about radiation, had never built a cloud chamber or thought about it before, getting them to a point where now, they had the confidence that if anyone asked them, they would know how it worked because they'd built it.

SARAH HANSEN: They'd built it.

ANNE WHITE: And that, I think, was really special.

SARAH HANSEN: Yeah. I mean, it goes back to the LEGOs and that spark that you had as a child. The hands-on building, and now, you're helping students develop their understanding of science through hands-on learning. And then, they really understand it because they've built it. But these things don't-- like, I'm sure you didn't just wake up one day and say, oh, I know. I'm just going to make this kit.

ANNE WHITE: Oh, no. No. I'm a scientist. Of course, I read the literature. So I did a lot of Google searches. So I watched a lot of YouTube videos and blogs.

I really am grateful to the great work that the CERN team does. They had a lot of really good stuff. And they have beautiful demonstration cloud chambers that can be built. So it felt, after doing some research, that there was a real niche, there was a real gap, and that was the gap I sought to fill.

So it was fun and challenging to see all the great work that people have done out there and really take from that and adapt it into something new. So it was really just like the research I do on fusion, just different. Research on cloud chambers, and well, let's build one that's never been built before. So that's what we did.

SARAH HANSEN: Yeah. No, I love that idea. I mean, I just think, sometimes, people think of MIT, and it's just like, geniuses doing these genius things, but I like to shed light on the fact that these are often like, years of work and research and building on what other people have done, and it's a collaborative effort. Science is a collaborative, major group project.

ANNE WHITE: It absolutely is. It is such a major group project. And to think that I have done a group project with Wilson, who created the first cloud chamber. I have now done a group project with all the students in my class with a cloud chamber which was used to discover positrons, and see antimatter for the first time.

So, yes, we are part of this grand collaboration of cloud chambers. And I feel very special to be a part of it. And so writing a paper about it was also very meaningful, to share what I've learned. And hopefully, others will read the paper and be inspired, or maybe use the techniques we used in their own classroom.

SARAH HANSEN: And just thinking about other educators who might be listening to this, do you have any advice for them if they want to create these kits and use them in their large lecture classes?

ANNE WHITE: Yeah. This could definitely work in a large lecture class. Just make sure you've got lots of assistants running around. So I was also very, very fortunate that we had recruited a couple of grad students and an undergrad who helped me hover around the day that we did it in the lecture class.

Because, again, you might be inserting this kitchen cloud chamber into a regular chalk and talk class, and you don't need any materials, but you are going to be carrying a big box of jars and sponges and alcohol into your classroom, and people say, what are you doing? And you've got this dry ice that you had to go and buy. Definitely, it works really well for a morning class, because then you get the dry ice in the morning.

SARAH HANSEN: So that's a very specific logistical piece of advice that is key.

ANNE WHITE: A lot of people are much better at this than I am. I was sort of like, I'm just going to go and buy some dry ice at Brooklyn Ice by my house and then drive it into MIT that day. But other people are really savvy and they're like, oh, we could have this delivered. And we have this infrastructure at our university, at our school to bring us this material. Great. Use it.

But if you're going to deploy it in a class, having students work in pairs worked out really well. That was good. I think any more than that, and there's not enough hands-on. Because it is, again, a small jar you hold in one hand.

And you got to get kind of close to it to look at it. And having people hovering around to help guide students if they're going off on really a bad tangential direction, kind of ask a few leading questions to nudge them back to the right spot where you want them to be, so that, ultimately, after two tries, everyone is successful at getting their cloud chamber to work. But it does fit in the 5-0 minutes, which is impressive.

SARAH HANSEN: Yeah. And that's exciting. And then, if you zoom out, make the connection for me between the cloud chamber kit and what you're trying to do with fusion. Like, how do you connect these two things together?

ANNE WHITE: Well, I think, for me, personally, it's about building things no one ever built before, so we're filling that gap, and also, measuring radiation in new ways. So in my group, one of my students likes to say, we build really fancy thermometers, and we passively sent the radiation that comes from a fusion plasma.

And so that's kind of similar to this. We built a not so fancy way of seeing ionizing radiation and looking at it passively with our eyes. So it's connected that way.

SARAH HANSEN: Yeah. Thank you. I'm curious, what do you want to take on next in physics education?

ANNE WHITE: Well, another thing I did in the class that I'd love to build on more was radiation-seeking robots. That was a lot of fun. I'd like to go back and work a little bit more on the radiation-seeking robots.

I'm really keen to understand how I can do more hands-on activities with machine learning in the classroom. So we did train some of the robots with some very simple algorithms. But talking to some colleagues about what we might do with a cloud chamber, and perhaps, video or image processing could be exciting.

Another thing I would plug, I'm not doing this, but some colleagues are, they're developing an extraordinarily inexpensive and simple to build Geiger counter which can plug into your smartphone. So my colleague, Professor Mike Short, is working on that. So he's probably someone who's crossed your path before. He's amazing.

SARAH HANSEN: He was our first *Chalk Radio* podcast guest.

ANNE WHITE: There you go. Everyone is a fan of Mike Short. Yeah. So there's a lot of things that I would be interested in doing next. But in terms of hands-on stuff, I don't know. I'm definitely still in robot land right now.

SARAH HANSEN: That was Professor Anne White, MIT physicist and instructor in course 22.011, Nuclear Engineering Science Systems and Society. You can find those course materials on our MIT OpenCourseWare website. As usual, they are Creative Commons licensed, which means you can use them freely in your own teaching.

You can also find her open access article on creating a cloud chamber kit for active learning in the journal *Physics Education.* We'll put the link in the show notes for you. Thank you so much for listening. Until next time, signing off from Cambridge, Massachusetts, I'm your host, Sarah Hansen from MIT OpenCourseWare.

MIT Chalk Radio's producers include myself, Brett Paci, and Dave Lishansky. Show notes for this episode were written by Peter Chipman. Anne White's OCW course site was built by Eliz DeRienzo. Jason Player makes our episode cassette animation on YouTube. We're funded by MIT Open Learning and supporters like you.

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