[MUSIC PLAYING]

MIKE SHORT: Instead of saying, analyze this theoretical problem, I said, analyze your toenails. Tell me how much arsenic and gold you've got in your body. All we study at MIT is the natural world and things we make out of it, so everything is reducible to practice. Everything can be real, if you put in the effort.

SARAH HANSEN: Today on the podcast, we're talking about ionizing radiation and nuclear engineering. How do you make these things real and tangible?

MIKE SHORT: Matter is a form of energy. And once that clicked, everything seemed to make sense-- radioactive decay, nuclear reactions, all these things. I remember that aha moment in this class that I teach as a second-year student back in 2002. And it's those kind of moments that made me want to stay in it, because I feel like, wow, I really know this field now.

SARAH HANSEN: Welcome to *Chalk Radio,* a podcast about inspired teaching at MIT. I'm your host, Sarah Hansen from MIT OpenCourseWare. The Nuclear Engineering and Ionizing Radiation course at MIT take students from understanding basic physics to grappling with the core concepts of Einstein's E equals mc squared.

In this episode, we're going to delve into how this is possible, and what it takes to make a class that's not only hands-on, but also capable of evolving daily. My guest is one of the main people that makes this happen, Professor Mike Short.

MIKE SHORT: This course is all about radiation, both its origins and its uses. So this is the first course on its intro to everything nuclear that any student at MIT would take. And a lot of times for students, it's their first modern physics course. The physics courses that first-year students take are often things that we've known for 100 to 300 years.

And the field of nuclear physics is still evolving. We're still using nuclear radiation spectra to detect the presence of water on Mars or the moon. We're still confirming our knowledge of which particles do and don't exist and why. So this is also intro to modern physics.

SARAH HANSEN: So nuclear science and radiation in particular are emotionally charged topics, you know? You read on the internet claims like, cell phones cause cancer, things like that. How are you preparing students to debunk pseudoscience and to really serve the public?

MIKE SHORT: We actually spent two weeks at the end of the class looking at studies that are false or have exaggerated claims and teaching students what to look for. So the first 11 weeks of the class, we teach the students the fundamentals of nuclear science. And then we turn to published articles, and blogs, and other things in the field.

And we debunk myths like cell phones cause cancer due to ionizing radiation. Cell phones don't emit ionizing radiation. We debunk myths like, the tiniest little bit of irradiation can harm you, when in truth, we don't have the data for that.

But a lot of misinformation in radiation and nuclear science is incorporated into culture, into our sort of collective consciousness, and even in what's called the linear no threshold model, which says, every little bit of radiation does harm. We don't know that to be true or false, and it's a good thing we don't. Because we would need to have exposed tens of millions of people to low levels of radiation in a controlled study, which is not something I think is ethically correct to do.

It's also not ethically correct to say that all radiation causes harm, because we don't know. And I want students to both recognize false science in the field, and recognize when we don't know enough information to say something confidently, and be comfortable with that lack of knowledge. It means there's something new to explore. But if you don't have something to conclude, don't draw a conclusion.

SARAH HANSEN: Uh-huh. How does this connect to the irradiated fruit party that have in the class? What is that?

MIKE SHORT: Yeah. The last day of class, we often have an irradiated fruit party, where I bring in fruit that could only be brought into the US because it's irradiated. So there are many fruits that are-- there many different types of produce, including fruits, that are irradiated, and it's the only known way to kill all of the insect, viral, and bacterial pathogens that can wreak havoc on either people or on our crops.

An interesting point of information, Hawaii and Puerto Rico, despite being part of the US, are agriculturally distinct areas, and you are not allowed to simply import produce from those. I had an apple confiscated from the airport in Puerto Rico when I learned that to be the case. However, if you irradiate foods, like, this is why we can get a lot of pineapples from Costa Rica.

We've started getting mangosteens in from Thailand, where I didn't know what that fruit was until a few years ago and now, you can find them at H Mart in Cambridge. A lot of this is because we can kill the pests, and it doesn't harm the food. It doesn't make the food radioactive. But a lot of this is to personalize the science.

So when students eat food that they may or may not known have been irradiated, they taste good. They seem safe. And it's one of those things where once it's personalized, it's not as scary. When you learn the knowledge and then you see it for yourselves, it becomes a lot more acceptable.

SARAH HANSEN: Yeah, learning through experience is very powerful. What does it mean to you for students to develop fluency in this field?

MIKE SHORT: It's important to be fluent in this field because a cursory knowledge of radiation science is not enough. I'd say there are a lot of self-proclaimed experts-- I call them armchair PhDs-- who have learned a bit of genuine knowledge, but then extrapolate it too far.

And that combined with all the things we've heard in pop culture, unfortunately sometimes from celebrities spouting falsehoods about radiation, or vaccines, or other things that they don't understand, people listen to other people, and people listen to role models and folks that they look up to. But it's important to be fluent and well-grounded in the fundamentals so that you can sort out fact from fiction.

And I want every student that leaves my class to be able to recognize something that's incorrect, even if it's told to them by a celebrity, an expert, a parent, a friend, anyone-- that they know what the reality is, and it shouldn't depend on the source it comes from. They should be able to tell whether it's real or not and verify if the source is genuine.

SARAH HANSEN: Uh-huh. And how do you help students develop this fluency?

MIKE SHORT: So it starts off with the fundamentals of radiation science. So like any class, we teach all the fundamentals from well-established theory. But along the way every week, we have labs and personalisation. Like, for example, the first day of class, I ask students to bring in their toenail clippings.

[MUSIC PLAYING]

And they usually say, that's disgusting. What are we doing? And I say, you'll see. We're going to put them in the reactor. And we irradiate their toenail clippings. And because to some degree, you are what you eat, some of the elements which we eat and we don't want to, things like arsenic, or selenium, or chromium, some of which can be good in small amounts, bad in large amounts-- others like arsenic, I'm not sure if there's a good use of it-- get incorporated into our toenails.

So we activate those toenails by putting them in the reactor. They absorb neutrons and give off characteristic gamma rays, giving away how many atoms of arsenic, and selenium, and such are incorporated into the toenails with striking precision. And so we're able to tell where students come from based on analysis of their toenails.

We had one student who had a lot of gold in their toenails. And I said, I thought I asked you guys to clean these off, remove any polish. And the student said, yeah, I did. But I live near a gold mining town, and it's in the water.

SARAH HANSEN: Wow, that's so interesting.

MIKE SHORT: So that's what I mean by personal, is they discover things about themselves through nuclear science. In the problem sense, instead of saying, analyze this theoretical problem, I said, analyze your toenails. Tell me how much arsenic and gold you've got in your body.

SARAH HANSEN: Right, right. So in the course, you make a point of saying that the method of instruction is often context first, theory second, and then context again. How does that relate to that method of instruction?

MIKE SHORT: This is an example of that method of instruction. I like to start by opening knowledge gaps rather than spouting theory that someone. It doesn't usually stick if I just say, here are some facts. Learn them. That's usually in one ear, out the other, if they're listening at all.

But when you show someone something surprising, they're fully engaged. They're always multi-sensory engaged. They're listening. In a lot of cases, they're touching, in some cases, even smelling. Taste is the sense that we don't tend to engage in nuclear science, with good reason.

[CHUCKLES]

But you can sense, and feel, and hear a lot of things in nuclear science. Like yesterday, I was with one of my graduate students. We were looking at some highly irradiated materials for a reactor in Idaho, and we heard this little faint buzzing noise in the Geiger counter. And if you put your ear up to the Geiger counter near the radiation source, you can hear tiny electrical discharges. You can hear the detector working.

And then I want the student to say, why is that? Why do I hear this fuzzy noise near the detector when it's working? Then when you explain why, students tend to remember. Not too many people learn well by being lectured at, but everyone learns well by opening knowledge gaps.

And you're effectively pulling the information in rather than us pushing it to the students. Something I learned from a mentor here is you can't push a string. You want knowledge into a student's brain, they've got to pull it. You can't push it.

SARAH HANSEN: You made a choice in this iteration of the course to offer students the ability to do analytical homework or take-home, hands-on labs. How did that work out? What does that look like in practice?

MIKE SHORT: Interestingly, I spent all this time making these optional labs. Nobody did them. So the next couple of years, I simply made everything mandatory. The students said they loved the flexibility. They're really psyched that I put in all this time to do the labs. But it wasn't for a grade, so they didn't do it. And so that's when I learned. If it's not graded, it's not going to get done.

So I made all the labs mandatory. I cut out a little bit of the analytics in favor of adding context before and after the theory, and retention went up. Grades went up, on average. And the course evaluations went up, too. So anything numerical we can get improved-- and in my subjective opinion, so did the students' knowledge of what's happening.

And that, I get from my colleagues, because I track these students as they progress through MIT, through our department. And my colleagues who teach further-on courses, the more advanced ones, can tell me whether or not the students really know the fundamentals that they're depending on. So far, things have been getting better, but it requires planning.

And it also requires a lot of thinking, where I'll look through my syllabus, and I have an empty column where the user doesn't exist in most syllabi, which is, what is this week's hands-on instruction? And I try to make sure that's full. So another example is if you want to know, do you have real diamond rings?

When we get to reading electron spectra and characteristic X-ray spectra, I could either give them a problem from theory, which is boring, or I can run some standard for them, where they know what to expect. Or I can say, that's a nice diamond ring. Do you want to know if it's real? And the student invariably says, absolutely, I want to know if it's real.

SARAH HANSEN: Right.

MIKE SHORT: So we have the student take the controls of the electron microscope and analyze it to see, does that diamond emit zirconium x-rays? Because if it does, it's cubic zirconia. If it emits silicon x-rays, it's moissanite or silicon carbide.

My favorite one was this day happened to fall on parents' weekend. So I asked the students, does anybody have a diamond ring? And one of the students' mothers said, oh, yeah. Let's check my engagement ring. And her husband was just, oh, gosh. What's going to happen? What's going to happen? He thinks he bought a genuine ring. It turned out to be real. We had the proof.

SARAH HANSEN: OK, that's good.

[MUSIC PLAYING]

Mike, can you tell us about the radioactive scavenger hunt?

MIKE SHORT: Sure. I challenge the students to find the most radioactive place in Boston. And each of them had to go in teams of two and pick a place that they thought would be radioactive based on what we'd learned about where you find radiation. So radiation, a lot of it comes from space, from cosmic protons that hit the atmosphere. So some students thought, I'll go to the tallest building, and I'll probably get more radiation.

Others had read about radon underground, because there are isotopes of radium emitting radon gas. And so they thought, we'll go down into the subway, get as low as we can go. Other students looked at the relative amount of radiation in different building materials, like wood, clay, marble, granite, and they went to the most granite-dense locations they could find, or the ones with the most marble.

And those are the students that won. There were places in Boston that have six times the normal radiation background, simply because they're made out of marble or granite. These include things like the state house and some fancy fountains around town. Did not know about the fountains, but they just thought, let's find giant chunks of stone, and they were right.

SARAH HANSEN: The hands-on experiences that Mike creates for students of his course are pretty unique. He told me that when he took this course as an undergraduate student at MIT, it wasn't typically hands-on. So I wanted to know what it's like to teach in a way that's so different from his own personal experience. What does it take to create such fascinating labs and lessons without a clear model from one's own educational background?

MIKE SHORT: It's natural. I teach the way that I learn, because I thought back on all my experiences and I thought, from which courses did I really remember a lot? And these were things like hands-on blacksmithing or laboratory courses. We did have a lab class where we counted a lot of radiation, and I remember those labs very well.

And I think back to my neutronics problem sets. I remember the theory OK, but I don't remember very many visual instances of that class. It just kind of happened. The knowledge is maybe in there somewhere. I don't know. But I know where I was when I did most of the hands-on exercises. And in the end, you can make anything hands-on, even neutronics that I mentioned.

So I at some point went skulking around places I oughtn't, like around in the reactor once I got access, and found an eight-foot pile of graphite that was behind a bunch of equipment. It wasn't hidden. It was just covered with junk. And I asked, what's that? They just said, oh, that's our subcritical graphite reactor pile. We're going to get rid of that next year.

So I sounded the alarm and said, you cannot get rid of this graphite pile. And then our neutronics professors Ben Forget and Kord Smith said, yeah, you're right. We can't. So they spent a whole winter restoring it with a couple of students. And now, it's one of the central labs in my class and in their class.

So we've taken the most theory-heavy, dry, and boring class and turned it experimental because you can. You're always studying the natural world, right? All we study at MIT is the natural world and things we make out of it, so everything is reducible to practice. Everything can be real, if you put in the effort.

SARAH HANSEN: Part of what's so special about this class is the dedication that Mike and his colleagues have to constantly improving it through real-time student feedback. And I don't mean fixing pieces to implement for the next semester. I'm talking about next-day transformations of class procedures. To accomplish this, Mike created the aptly titled Rants Page.

MIKE SHORT: The Rant Page is an anonymous, simple, PHP comment form that I wrote, where I want students to tell me things that they want changed. Because I try my best to collect in-person feedback from the students both one-on-one and in class. But some students don't feel comfortable telling a professor, I don't like what you're doing. So I give them a place to do so completely anonymously. It ended up being 20 lines of code. It wasn't hard.

And what I started getting was real-time feedback about, I can't read your writing. So then I know to slow it down. Or, I really wish you wouldn't slow the class down for this one student's incessant questions, so I know to limit each student to a few questions if it gets to be too much. And I would address them in class to say, it's safe to address this, because it's anonymous. I have literally no way of knowing.

But if one person wrote it, probably a lot of you are thinking it. And the students responded positively to say, wow, it was really nice to know that we'd make a suggestion at 2:00 in the morning, and then by 10:00 in the morning, it would be addressed. The class would change in real time, and they knew they had the power to shape their own learning.

[MUSIC PLAYING]

SARAH HANSEN: With all the buzz around this course, we had a ton of great questions come in from educators and students alike. So we picked out some of our favorites and posed them to Mike. Number one, what math do I need to understand this field?

MIKE SHORT: That's a good question. It depends on how deeply you want to understand the field. If you want to pass my class, if you want a get an A in my class, you don't really need much math beyond single-variable calculus. And even then, it's not very much. I think we use-- we have one or two lectures with integrals and a few lectures with differential equations, but linear first order things that you solve in calculus one.

SARAH HANSEN: Number two, when you were a student, how did you deal with courses that didn't seem interesting to you, but that you had to study?

MIKE SHORT: That's a good question. I have a few answers to that. So for courses that didn't seem interesting that I had to study, if I knew why I had to study it, there was at least a practical reason to do well. For example, for me, it was neutronics.

Neutron transport is one of the things that makes nuclear engineers what they are. I found it to be dry and not very real-world, because I knew I was never going to be a reactor designer. But I felt I would need to understand neutron transport and power levels in order to be an effective nuclear material scientist. Luckily, I was right.

For the classes which I just had to take because they were requirements, and I had no reason to want to take them, I got a little sneaky. I ended up double majoring with material science and wrote a petition to get out of this one medical imaging class and replace it with 12 others in order to make a second major. And that petition was approved.

So I actually did get to simply drop a departmental requirement by articulating why I wanted to study something else. Not all students realize that they can do this, but they can do this. With a very good intellectual justification, rules can be bent or broken.

SARAH HANSEN: OK, number three. Why can't we just send nuclear waste to space?

MIKE SHORT: We could just send nuclear waste to space and get it out of our hair. It would be expensive. It costs a lot of money per gram to get something off the planet. Someone has to agree to pay for it. And what worries me most is, what if one of those missions goes wrong? What if you're launching a rocket full of the world's worst nuclear waste, and something goes wrong at the launch, and then it comes back down, along with the rocket explosion? Then you have contaminated the planet.

So I personally believe in containing nuclear waste where we can see it rather than blasting it off into space and contaminating space, unless we know where it's going, and that nothing will go wrong. Because a lot of folks are worried about the dangers of radiation, how we're going to deal with nuclear waste. And I don't fear nuclear waste, but I've got a healthy respect for it in that whatever we do with it has to have the lowest probability of getting out and contaminating anything.

I think it's a necessary thing to make in order to make nuclear power. So if we want to make almost unlimited carbon-free power, we're going to make waste in the process. You can't fight thermodynamics. You're always going to have some waste of energy or something else. But then what you do with it has to be very carefully considered. And it sounds simple to blast it into space, but then you have to think, what could go wrong, and who could I hurt if it goes wrong?

SARAH HANSEN: Number four, what do you think about the cultural and political idea against nuclear power?

MIKE SHORT: To me, the current cultural and political idea against nuclear power is not grounded in fact. It's grounded in emotion. And I've talked with a lot of folks who either know very little or very much about the physics and engineering of nuclear power. But I find more often than not, it's an issue designed to rally a base.

Strangely, I've never really understood this. So many environmentalists are against nuclear power. And I'm an environmentalist, too, which is why I'm for nuclear power. So I find the anti-nuclear sentiment to be so strongly democratic and the pro-nuclear sentiment to be so strongly Republican, neither of which is for reasons which I'm willing to accept. They seem to be more about political tribalism than fact.

And it's interesting now that for the first time since we've had Chernobyl disasters and such, more and more environmentalists are coming out in favor of nuclear power, not because they're in favor of radiation, and waste, and such. But the goal is to prevent climate change.

I would much sooner take a risk of something going wrong with nuclear power than definitely lose the battle to climate change. Everything to me comes out to minimizing risk to human life and maximizing quality of life. So to me, the risk of nuclear power is that if we can go all carbon-free for energy, we can reverse climate change.

If we're afraid of using nuclear power for fear of the waste getting out, or the risk, or the weapons, then we're automatically losing the war, and we're going to have an uninhabitable planet anyway. And we can't get off this planet yet, and then we'll go make the same mistakes there as we would here.

For example, I came into this department wanting to study fusion, felt it wasn't ready yet, so I spent a lot of my time on fission, thinking, this is going to be the bridge to fusion. Because fusion promises more carbon-free power with far less radioactive waste, but not none. And I'm willing to accept the some, so as not to lose the climate change battle, which is already on our doorstep.

I do worry that many environmentalists lose sight of the real goal, which is protecting the planet. And to me, protecting the planet doesn't mean, do no harm. It means, do as little harm as possible while preserving our quality of life.

SARAH HANSEN: Number five, while learning, occasionally, you will have these moments where all of the sudden, the dots suddenly connect, and a previously challenging topic becomes seemingly perfectly clear to you. Could you share with us one of your brain blasts?

MIKE SHORT: Let's see. For me, it's the same one that most students get at about the one-month mark in my class, and that's energy is matter, that E equals mc squared. You see it on shirts all over MIT. It's probably the one equation that everyone in America knows, but not a lot of people really understand that the conversion of matter into energy through ionizing radiation is the movement of energy from one form to another. Matter is a form of energy.

And once that clicked, everything seemed to make sense-- radioactive decay, nuclear reactions, all these things. I remember that aha moment in this class that I teach as a second-year student back in 2002. And it's those kind of moments that made me want to stay in it, because I feel like, wow, I really know this field now.

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SARAH HANSEN: If you're interested in learning more about ionizing radiation, we've got all of Mike's course materials on our site. You can find us at ocw.mit.edu. You can also read more of his instructor insights on his OCW course page made especially for educators. You can find all sorts of different instructor insights on our educator portal at ocw.mit.edu/educator. Until next time, I'm Sarah Hansen from MIT OpenCourseWare.