[SQUEAKING]

[RUSTLING]

[CLICKING]

R. SCOTT KEMP: All right, good morning. So when you all started this class, you probably had one image of nuclear power. And maybe you had some questions, maybe not. If you were a nuclear engineer, I hope you still have some of that excitement that brought you to nuclear engineering.

But I also hope that you feel you have a little bit more of an even-handed view of the issues facing nuclear. More important, however, than the details that we discussed over the course of this semester is simply to make the observation that many of these issues are still largely ignored in the nuclear engineering community writ large.

Now, this department is actually getting a lot better about talking about and designing for things like economics and so on. But that's not necessarily true of the nuclear engineering community in general. The challenges that we covered, I would argue, obviously, are real, and you may not agree with my characterization of them. And that's OK.

But I hope you will appreciate that, whatever the problems are, we can't just ignore them out of existence. They will not fix themselves. We really have to address them head on. And one of the reasons the nuclear community doesn't seem to want to do this is that, frankly, it's hard and unpleasant work, as you've experienced over the course of this semester.

But if you think about it, that actually tells us something else about ourselves. It tells us that our community, in our expert judgment, is not free of emotional bias. We've come to this issue with certain beliefs and hopes, and it colors our thinking on the matter.

If it were not so, it would not have been unpleasant, which gives rise to a question-- how should we make public policy around nuclear energy? Who should decide what actually happens in terms of new build? Now, in a democracy, generally, the public has a large voice.

And traditionally, the view has been that the public hasn't always been ultra supportive of nuclear. Maybe they don't really know what they're talking about. Experts, while not informed of all of the facts, generally know more about the issue at hand and are well placed to make a policy recommendation. So that's a vote in favor of putting policy making in the hands of the experts.

On the other hand, the expert community, as we've just talked about, is self-interested, right? It wants to promote whatever it is that leads to their professional success. So if we look at the world-- oh, I'm getting ahead of myself-- if we look out in the world, what do we see as an example of what works?

Generally, the expert-led approach does work. So we trust experts to help us regulate pharmaceuticals, to fly airplanes, to do all these things. But when it comes to matters like nuclear power, it seems like the public isn't necessarily on board with taking the expert recommendation.

What is it that causes this divergence between these two types of issues? That is the question for today. This is our last and final lecture in this course. And most of what I'm going to talk about today comes from work done by Howard Margolis, just to give him credit. So let's begin by looking into this expert lay-opinion divide.

So the first observation is that it's not normal for the public to say-- all experts are self-interested and I can't trust them. The public goes to doctors and has experts perform surgeries on their body. They go to lawyers and have experts advise them in matters of law that determine their success in life. We willingly put our lives in the hands of experts on a daily basis. So we can observe that it's not a problem of trusting experts in general.

There's a class of social problems, though, where the community doesn't trust experts. So many experts would advise you-- don't drink any alcohol, any actually. It used to be thought that a glass a day or something of wine was actually good. But now the recent research says any amount of alcohol is terrible for you.

Experts, would advise us not to eat fast food. Don't eat McDonald's. And yet, people don't listen. They're happy to drink alcohol and put processed food in their bodies. Now, it's important to note here that in these cases, perhaps the public is not always the most fearsome group. It's not just a case that the public is always scared, and experts are not scared.

In these cases that I just gave examples for, the public is willingly taking on risks that experts advise them not to do. So it's not just that the public is fearful. It may be that in some cases, people are willing to disregard expert advice because their personal preferences are elsewhere.

I know that drinking alcohol is bad for me, but I really enjoy having a beer. And I'm just going to decide that my short-term gains outweigh the long-term risks. So it's not actually an issue of not believing the experts, it's just my priorities are different. I need that nicotine hit if I'm a cigarette smoker.

But then there are these cases where the public really doesn't actually believe the experts are right. So these, we tend to think of them as more fringe, but they exist, like the people who deny evolution or climate change or are skeptical of vaccines. So in these cases, there's actually no acceptance of expert legitimacy.

But if you think about these cases, when people disagree, they don't disagree on the basis of facts or logic. The people who are vaccine skeptics aren't going around and saying-- I'm concerned about mRNA vaccines because the carrier lipid might not be fully metabolized and decomposed by the P450 cytochrome.

This could cause some issues with my liver down the road. I don't ever hear that argument. It's usually some kind of fringe idea that is not rooted in logic or evidence. So let's take these two as axiomatic aspects of the debate. It's not trusting experts in general, and it's not a dispute based in logic or facts.

So, what, then, explains what's going on? So if you ask around, if you look around, you tend to come up with three basic theories that are in the literature. So the first theory goes something like this.

This often happens, this is the theory that you'll most often get if you ask subject matter experts like your other professors. They say, well, the problem is really a trust deficit. The public, for some reason, has lost faith in nuclear experts' ability, and so they are no longer able to evaluate the real risk.

For example, perhaps because of TMI and Chernobyl and Fukushima combined with sensationalist media attention, the public now believes that nuclear engineers are just incompetent, and so therefore they've lost trust. If we could only find a way to get that trust back, then we could explain the virtues of nuclear and all would be well. That is often an explanation for what's going on.

There's another theory, which you will find not among the subject matter experts, but typically more among social scientists. And they'll say, actually, it's not about trust. It's not about experts. It's not about risk. These are actually distractions. The facts being debated are just rhetorical devices being lobbed at each other.

The proponents of this theory say it's really about ideology, about your identity, and who is being served by these policies. So the public looks at nuclear energy and they say, is this thing really helping me? Am I benefiting from this scheme of corporate billionaires who are aggregating all this money and building this plant and upping my electricity bill? Is this really in my interest?

They make safety claims. Should I trust them? Maybe they're just advocating for their own financial interests and they're not really telling me the truth. So this is a theory that is based on this question of who is being served, not what is being done, but who is benefiting.

The third explanation that we can find in the literature is a bit more subtle. We call it rival rationality. And it takes the view that experts in the public are both well-intending, they're both doing their best with the information that they have, it's just that they have actually different ways of understanding the world.

So for example, experts want to have safe reactors. And when they evaluate safety, they're going to look at safety in a way that they can understand, that they can measure and quantify it. So they'll say, well, what is the statistical risk of a cancer death per terawatt hour of electricity produced? That, to them, seems like a good way of thinking about safety.

The public is also interested in safety, but they have a different way of understanding what it means to be safe. For them, a safe reactor is a reactor that they don't have to worry about, a reactor that provides a sense of well-being, perhaps doesn't have the risk of a catastrophic event that they don't understand, perhaps something that seems not to disturb their pristine environment or to create liabilities that extend beyond their lifetime into their children's lifetime that they don't want to leave behind.

They're not necessarily opposed to the technology, but their idea of safety is not statistical cancer deaths per terawatt hour of electricity produced. Neither side is wrong here. It's just that they value different things and therefore they disagree on the bottom line.

So we have these three theories to try to understand this divide between the experts and the public. So let's just-- yeah?

AUDIENCE: I would also add a fourth thing. I don't know if it's [INAUDIBLE]. But the people who work on nuclear policy are not [INAUDIBLE]. The people that are [INAUDIBLE] some lawyers and scientists.

R. SCOTT KEMP: Yeah. This is true. But is this a theory for why the public doesn't agree with the experts?

AUDIENCE: In my own hypothesis, based on a [INAUDIBLE] of the European Commission Nuclear Policy, I think it is. And it ties to the fact that policymakers don't really do a concerted effort to educate the public on nuclear.

R. SCOTT KEMP: OK, we'll get back to this in a moment, about educating the public in nuclear. For the moment, let's proceed with these three theories and see which one is right. So all of these models seem to have explanatory power. They seem to characterize the debate. None of them seem obviously wrong.

But if these theories are going to be useful, they have to do more than just characterize the debate. They have to be able to predict when a technology is going to enjoy expert lay-public consensus, like flying airplanes, and when a technology is not going to enjoy lay-public consensus. Without that predictive power, they're not necessarily true models.

So let's investigate which of these models actually can predict the outcome. So let's pull number one apart a little bit more. Is it that we don't trust the experts themselves or we don't trust their conclusions? Now perhaps we worry about the DOE or NRC because we think these bodies are just populated by industry cronies and bloated technocrats who only want to support their private interests.

In short, they're just self-interested liars. But if that's the problem, then it's not about trust. It's really more Theorem II, ideological opposition, who is being served. So maybe that's not the nature of the trust deficit. Perhaps the issue is that the public feels that the engineers have their facts mixed up.

But remember from our previous slide, the disagreements are almost never rooted in actually discussions of facts or logic. So that doesn't really hold either. So if they don't disagree on the facts, perhaps they feel that the experts haven't captured all the facts. They agree on some facts, but there are other facts.

Well, actually that's rival rationality. So every time you try to pull apart number one, what winds up happening is you wind up in one of these two or three, these other theories. So number one is really just a way of saying-- there is mistrust. For some reason, the public doesn't agree with us, but it doesn't predict anything. So this is not a theory with predictive power.

Let's try theorem number two, ideological opposition. So to understand ideology, it's useful to decompose this a little bit further. And there's a lot of ways to do this. But I'm going to suggest we adopt an approach that was offered by Mary Douglas and Aaron Wildavsky. They were an anthropologist and political scientist who joined forces and tried to create a typology of ideology to describe how people think.

And it's not the only model out there, but I don't want to pick winners, but we need a model. So here's what they suggest. We can think about ideology as being broken into several groups. So the first ideological way of thinking are the hierarchicalists. So the hierarchicalists are people who prefer rule by the elite.

Now that elite can be a priest class. It can be nobility. It can be an intellectual elite. It can be blue ribbon commissions. It can be the plutocracy of Wall Street. Whatever it means is that there's some group of people who, for some reason, are imbued with a special ability to make decisions on behalf of the public. These are people who think along these lines of hierarchicalists.

So we can have extreme examples from history. Fascism and theocracy are hierarchical rule. Conservatives tend to be hierarchicalists. The Judeo-Christian ethic and Confucianism are hierarchical epic structures. You can see all these throughout all of history.

Another way of looking at the world is the egalitarian approach. Now, egalitarians are notionally democratic. They are the revolutionaries concerned with fairness and justice and equality for all and due process and so on.

And we see the examples of this throughout history in communism, in liberals, modern liberalism, polytheistic epics like Hinduism, *Gilgamesh,* Greek mythology all tend to have this egalitarian quality in those epics by virtue of human frailty as being assigned to gods and so on. So the idea here is it's really about uniform benefit and risk.

Then we have the entrepreneur class. The entrepreneurs are not concerned with identity groups or relations among people. So the first two are inherently concerned with how the power between people is arranged. And the third category, the entrepreneurs, they're actually concerned with maximizing some exterior variable.

That variable could be wealth generation, it could be technology, progress of some kind. And they, therefore, prefer whatever it is that allows that variable to be maximized. Usually that's loose correlations with minimal rules and norms to allow freedom of action. These are the Elon Musks of the world.

Historically, we see this in anarchism, libertarians, postmodernist, nihilist, so on and so forth. So if we accept this as a kind of topology for describing ideological orientations in the world, do they tell us anything about what technologies will and will not enjoy lay-public expert support? So if you think about it, nuclear power has qualities where it cannot succeed without a highly hierarchical structure.

It requires the aggregation of enormous resources among a small number of people. It requires an engineering elite. It requires strong centralized government for safety and rules. So you would think that people who were hierarchically inclined might find nuclear power to be quite acceptable, and therefore the people who are egalitarians might find it to be morally wrong.

The entrepreneur might find the underlying physics cool, but at the same time, might see that fission is outdated, and maybe the future is all fusion, which is all cool and about new technology maximization or something like this. So that would be the way you would predict nuclear would break down.

But here's the problem. If you go and survey experts in the nuclear community, they don't all fall into the hierarchicalist class. Generally, the people in this classroom will fall among all three of these categories.

There are plenty of liberal-minded individuals, egalitarians, who are in favor of nuclear energy. There are plenty of hierarchicalists who are not. For example, there tends to be a lot of Christian religious types in the United States who are both very hierarchicalist and also opposed to nuclear energy.

There are a lot of tree-hugging, green people who want to address climate change, who consider themselves egalitarians and also support nuclear energy. Obama, who is arguably egalitarian as they come in the American political system, gave a lot of billions of dollars to nuclear energy.

So while these ideologies may explain aspects of the divided opinion in our expert community, they don't do a very good job of actually predicting which technologies will enjoy this expert lay-public agreement or disagreement. So this also doesn't seem to be really aligned and therefore also not a very good predictive theory.

So let's look at this third one, rival rationality. So it's clear that if you talk to the experts and lay public, the issues that they're going to raise, the metrics that they're going to discuss are, in fact, not the same. That's pretty clear. And I mentioned, experts having these well-defined risks, like cancer deaths per terawatt hour, person-rem, and so on.

They like this precision. And that often misses societal concerns. And not all effects are radiation. But our reductions can sometimes be a little absurd when we're trying to come up with our measurable ways of understanding. So that's a given. For the public, risk perception is a much more complicated process than the process that we tend to measure in this class or in our classrooms.

So how do we understand this public understanding of risk? So there's a psychologist who investigated this question named Vincent Covello. And he produced this list of risk correlates. So what are these things? These are heuristics, basically, experience-based rules for how humans might evaluate the risk of a situation as it arises.

And when we go through this list, we'll find that there is actually a relatively strong correlation between what things we hear nuclear skeptics saying and the things that are in the column Increased Public Concern. So you can go through this list yourself and decide how you think nuclear power shakes out. But I will color it as I think nuclear power shakes out.

And you can see that there are a lot of heuristic measures that would predict nuclear power, which would tell people nuclear power might be risky. So let's just look at a couple of these. Does it have catastrophic potential, where the fatalities are grouped in time and space or are they scattered? Absolutely. Nuclear's issues are catastrophic when they happen. They're rare, but when they happen, they're catastrophic.

Is the mechanism of harm unfamiliar or familiar? It's pretty esoteric. Radiation, you can't see it. If this were a car crash, we would be talking about catastrophic potential, fatality scattered. Familiarity of mechanism is very obvious-- body will slam into hard object. Very easy. The mechanisms are esoteric. Is there scientifically certain or low certainty in the risk?

Is exposure voluntary or involuntary? You can go on. I drive my own car, I take risk into my own hands. Not true with some nuclear power plant being operated. Just go through this list and you'll see that, yeah, nuclear just doesn't come off on the right side of the equation.

So at the end of the day, we all know that actually driving cars are a lot worse than nuclear power. The odds of an American dying in an auto accident is 1 in 107. So 50% chance that one of you in this classroom will die in a car crash. That's brutal. But people are fine with that. And how?

So it seems on the surface, actually, we have struck paydirt. This really does seem to be a description of decision making that is entrenched in the human psyche that explains how it is people come to see the world. But if this were the final answer, it would mean that the public cares about many factors beyond what we care about. And that conclusion should give you some pause because you were once people, too.

[LAUGHTER]

You should have all of these same inborn traits, you pro-nuclear people, as the rest of the public. So what is going on? And number two, if this were also always the case, as it were, it would mean that the only way to win broad popular support for nuclear power would be to somehow assimilate all these weak-minded, emotional people into our superior technocratic empire.

We would have to become the Borg. And thankfully, we are not the Borg. So while Covello's list does, in fact, have predictive power finally, it doesn't have much explanatory power. Why does it not describe how it is that nuclear engineers don't suffer the same preferences as the rest of the public?

So to understand why this divide emerges, we need to look not at the superficial debate, but at a more fundamental process. And that process is the process of human cognition. So how do humans interact with the world? How does any animal interact with the world?

The answer, as we now know from all our work in AI, is through pattern recognition. The brain is a massive pattern-recognizing device. And patterns cue responses, and those cue actions and cue thoughts to help us understand what is going on.

So where do these responses come from? Some of them do indeed come from genetics. So almost all animals, I think all animals know how to eat from the moment they are born. They don't have to be taught how to eat. But other patterns arise through a process of learning, which is basically building on your experience.

So when you see this arrangement of squiggles, you immediately know, because you've been taught, that this is a differential. So something has created this pattern-matching process for you. So it's fair to say that patterns elicited in experts might be different than patterns elicited in the public because they have had different education. We get that.

Now this pattern-cued process of judgment is generally highly effective when it is applied to stimuli that are inside our realm of normal experience. We need to cross the street safely, we learn to look at the light.

It turns green, or the little white walking guy turns on and we walk and it works over and over. And it works at all the intersections, even if the sign is turned this way or if the intersection is two roads or four roads or five roads or whatever. We're pretty good with that.

But sometimes pattern recognition can foul up. So let's just explore that a little bit more. So you've probably all seen this optical illusion before. And if I asked you to study carefully the length of the horizontal line in both images, I suspect for most of you it will appear that the line on the bottom is a little bit wider than the line on the top.

And then you know that, in fact, that's not true. So there's some kind of weird optical illusion that's happening. Why does your brain tell you this? The argument goes that you live in a 3D world, and it sees these diagonal lines as the edges of a box, of a three-dimensional surface. And it is adjusting the perceived length of the line based on the fact that you interpret the world in 3D.

This is a 2D puzzle. It's a mismatch for your interpretive engine. So we can generalize this and say-- there are these distribution of problems in the world and many of them fall within our normal experience. But then we get into these types of puzzles that fall on the tail end, either because they're at some scale below where we exist as humans, or some scale above where we exist as humans.

So for example, quantum mechanics-- not exactly within the range of normal human experience. Very difficult for people to understand why quantum things do the things that they do because it just disagrees with our everyday experience. And these are puzzles of the laboratory. The same is true for phenomenon that exist at much larger scales that transcend human existence.

So I like to give the example of macroeconomics. What do you do when the economy is running into a recession? You spend more money. That does not make sense to a lot of people. And you have a lot of political officials, for example, in Great Britain and Europe, advocating for austerity policies of not spending, which only makes the recession worse.

This is this counterintuitive thing where for an individual, when you don't have money, you want to save the money. But when you're talking about national policy, in fact, the opposite is true. And so people really struggle with that. So nuclear power has a lot of qualities that fall both over here and even some that fall over here, e.g. radiation damage.

And so it's really quite difficult for people to use their normal heuristics to evaluate the risks associated with nuclear power. So let's do a little experiment to see if this actually has any merit and maybe learn something about how to change people's opinion. So we're going to experiment on you.

I'm going to challenge your conclusions. I'm going to give you a question, a little test, and challenge your conclusions, and we'll see what your ability is to reason and what effect it has on you. So you need a pencil, paper, or something like a computer to write your answers down, just some way to write down an answer. You don't need to turn it in. You just need to write down an answer.

All right, here's how it goes. I have a cup, and in this cup I have three poker chips. All right? I will wait for people to get their paper. Because you need to hear the problem. You ready? OK. I have a cup with three poker chips in it.

The poker chips are as follows-- one is blue on both sides, one is red on both sides, and one is red on one side and blue on the third side. I remove one poker chip from the cup, and I put it on the table. And without lifting my hand, I ask you, suppose the top of the poker chip happens to be blue? What is the probability that the bottom is also blue? Write down your answer.

Same question starting with replacement from the beginning. I pull out a poker chip. I put it on the table, put my hand on top of it, and I say, suppose the top of the poker chip is red. What is the probability that the bottom of the poker chip is also red? Write down your answer.

Third question-- poker chips will go back in the cup. Pull out a poker chip. Put it on the table. And I say, what is the chance that the chip has the same color on both sides? Write down your answer. OK, let's check your answers. Hands up if you got 1/2 for questions 1 and 2 and 2/3 for questions 3. Higher.

Keep your hands up. Sorry your arm's going to get tired. Now, what if your neighbor suggests that all the people with raised hands are contradicting themselves? Keep your hands up. Think for a second. If you believe your neighbor tells you you're contradicting yourself, put your hand down.

Now, Professor Kemp walks into the classroom. He's wearing a sports coat, so he must know what he's talking about. Here I am, and I say earnestly, that, in fact, the answer to all three questions is, in fact, 2/3. Those who answered 1/2 for the first and second question, you're mistaken. Wow, a lot of people trust authority here. OK, a couple people still have their hands up.

Everyone who has their hands up isn't quite ready to trust. They trust themselves first. OK, everyone relax. Let me rephrase question 1 and question 2. What is the probability that the color on the top matches the color on the bottom? Is that the same question as question 3?

Do you change your mind? Who has changed their mind based on that? And if you have changed your mind, stand up. 1 and 1/2 people. OK. Let's do the experiment. So we have three coins. Here's the truth table.

We have-- chip number 1, heads and tails; chip number 2, heads and tails; and chip number 3. I'm going to write it tails and heads. I don't know why. That's how it is in my notes. So here's the top of the coin or the top of the poker chip and the bottom of the poker chip.

And so this first one is going to be red and red, red and red. So heads means the heads comes up when you pull it out. Tails means tails comes up when you pull it out. The second one is blue and blue. And the third one is blue and red. And if it comes out the other way, it's red and blue.

So what this shows is if the top is blue, there is a 2/3 chance that the bottom is also blue. If the top is red, there's a 2/3 chance that the bottom is also red. And 2/3 of the coins have the same color on both sides. The answer is always 2/3, no matter what. All right, annoying.

So let's have a few moments of introspection about what just happened. I first informed you that I was going to give you a test, and I showed you a puzzle. I showed you these lines and I warned you that there are cognitive illusions to be had among experts.

And still first, until I explicitly challenge your intuition, most of you were probably quite satisfied with your answers of 1/2, 1/2, and 2/3. Some people didn't answer that way. Congratulations. Hopefully you didn't answer 3/4. Then, when I said, as the expert, that the answer was actually 2/3, only a small number of people, just based on me telling you, were willing to change their opinion.

Then I tried to appeal to some kind of logic. I made an argument that the questions were all actually logically equivalent questions. And people suddenly were like, ah, maybe that's right. I'm not sure. But not everyone was willing to change their mind right away.

And then I showed you the puzzle, and I think you all now believe me, I hope, given the truth table. But you probably have-- oh, that's still wrong? [LAUGHS] You're like, no, it can't be right. Something's going on. Does everyone understand this? If you don't understand it, then I'll explain it to you.

I guess the lining up of my lines is not very good. That doesn't help. The fourth insight is that we have remarkably little understanding of why we got it wrong. Why did we make that decision? Why did we hesitate to change our minds? These things are not exactly totally clear to us in retrospect.

So there are decision-making processes that are actually hidden from your conscious mind. They're happening at the subconscious level. And about 30 milliseconds later, your conscious mind absorbs the answer and provides a rationale for why it is the way it is. The pattern machine operates behind the curtain, as it were, and so it's really, really difficult to recognize when we are making these cognitive mistakes.

And don't get caught up with the idea that only the public is susceptible to making these kinds of cognitive mistakes around nuclear power. You are all MIT students, and you should know how to do combinatorics of the simplest kind. You are experts, and still mistakes are made.

So unfortunately, when these sort of counterintuitive puzzles show up at a social scale, we get stubbornness in political debates and harmful policies where people are certain of their views but haven't actually based those views on careful analysis of the facts. And this happens whenever we have something that doesn't line up, where the truth doesn't line up with those columns in Vincent Covello's list.

So by understanding this pattern matching in human responses, we've explained-- one, how people arrive at their judgments and, two, why they can't see the errors in their thinking for public and the scientists both and, three, why expert opinion and the appeal to logic isn't very effectual. This is why we can't, as was earlier suggested, just go explain nuclear power to the public.

Because this is not how they make their decisions. It's not based on your logical arguments. It's based on these other inborn qualities of evaluating risk. Don't feel bad that as MIT students you got it wrong because the scientific community gets it wrong all the time. So for example, the Copernican revolution in the second century, Ptolemy explained that the Earth was at the center of the solar system.

The sun went around the Earth, and the planets also went around the Earth in epicycles. And this was accepted as the explanation for 1,400 years of science. Now, the idea that the Earth could go around the sun was mathematically available to them. They could understand that transformation, but people just didn't believe it because it didn't agree with their everyday understanding of the world.

It wasn't until the 15th century where Copernicus comes along and says perhaps the solar system looks like this. And even then, it took 200 more years for the scientific consensus to change. People are really stubborn when it doesn't appear to resonate with their everyday experience.

So the philosopher of science, Thomas Kuhn, made a whole career on this. He wrote a book called *The Structure of Scientific Revolutions,* and he quite elegantly shows that scientists don't do science. Scientists kind of approximate science through a process that is inherently socially constructed.

Our views on what is a good experiment and how we should measure that and what level of statistical analysis is adequate, these are all socially constructed ideas and they heavily color how we look at a problem and the answers that we are willing to accept as valid and the questions that we're willing to ask. So scientists and experts get it wrong.

The existence of the disagreement between the expert community and the lay public does not mean always that the lay public is wrong. It just means someone is wrong. And this can be extra difficult when getting it wrong is essential to your survival.

So there's a author by the name of Upton Sinclair who famously wrote, "It is difficult to get a man to understand something when his salary depends on him not understanding it." So what we do know is that there is a process of learning that goes on among experts, one way or another, and it is powerful enough to overcome these.

That's how you guys became pro-nuclear in the first place, if you are pro-nuclear. So let's look a little bit more at how that actually does come about. So political scientists love this. This is a 2-by-2 matrix. We have, across the x-axis, the idea of technologies with low opportunity versus technologies with high opportunity, technologies with low risk versus technologies with high risk.

And if you're in this category, you don't care anything about that technology because it's of low benefit and it's of low risk, and who cares? And if you're up here, you're thinking, hmm, OK, lots of potential benefits but lots of potential risks. How do they trade off? And so you're having to do this hard mental calculation of adjudication.

So the idea is that whenever we are introduced to a technology, we start out down here because we don't really know anything about it. I heard about the internet. There it is. And then what happens is we either pursue one of two paths. Perhaps you're a person who learns about the technology and how great it is and all the amazing things AI is going to be able to do, and you're like, this is awesome, we should pursue this.

And then people are like, oh, but AI safety, other things. And maybe you're like, oh, OK, huge energy bills. And other people are going, I heard about this nuclear thing and it looks so dangerous. And I don't like it. And they go into this category. And then people are like yeah, but climate change. I'm like, oh, maybe.

So basically, you guys are on the green trajectory. Something happened in your history where you were more readily exposed to arguments that nuclear power was beneficial before you started thinking about all those other things. Whereas other people just went and relied on those inborn heuristics and they're like, oh, Three Mile Island and radiation and this is difficult. But you were systematically educated about the nature of science and all of these things, and so you took a different path.

So how do we change people's minds? Well, the fact is, most people are, in fact, lost forever in one of these boxes, either here or here, but not everyone. Some people are able to change their minds. And let's look a little bit about how that works.

So in much the same way that we have this list of predictive heuristics for risk, Vincent Covello's list, there's also a hierarchy of who do people trust. And they tend to trust entities that are just closer to them. So their own personal experience will always be the most, then their friends and family, then their identity group, the things that are common knowledge, and then some strangers standing on the street corner telling them about the aliens.

And so you can see why the Copernican revolution took 1,400 years. They look at the sky and says, I see the planet's doing loop-de-loops. And they talk to their friends and family in the scientific community, and they say the same thing. And there's nothing to change them.

And then this guy comes along and he's like, no, no, you've got it wrong. And they're like, [LAUGHS] please go away. Poker chips puzzle-- you were in disbelief when I suggested that if your neighbor told you that you were wrong, would you change your mind?

More people were willing to change their mind when I told them the answer because I'm a little bit higher up on this chain, arguably. The challenge for us is to figure out who can help bring the other side through this sort of risk matrix to help understand. And it explains why people who are nuclear engineers and not known to the general public are not very effective in changing people's minds.

So let's just quickly recap. Appeals to authority in our capacity as experts don't seem to work. Appeals to logic and facts will work, but primarily with other experts and also very slowly, as we observed. Poker chips, I asked you, is this all logically the same question?

And there was this, uh-- you have to refactor the weights on your neural network. And it takes time to do that. But ultimately this does work with other experts because we share a common epistemological basis.

This is the whole point of this class, is to try to use science and engineering calculations to address some of these social debates in a way that you get a little more insight into what's going on as engineers, because you believe the math. That's the one thing I have going for me in this class. Most of you will believe the math.

And then finally framing issues in a way that appeals to existing patterns of cognition does, in fact, work very well. This can be the inborn patterns in Covello's list. Sometimes it's hard for those things to be changed about nuclear, but we can emphasize the few that were in the right column. Remember, there were a couple.

Sometimes it takes the form of a TikTok video showing someone of the same generation who's excited about something. Identity group telling you that you should like something. And so people are like, oh, yeah, I recognize this 19-year-old and I'm a 19-year-old, and therefore this is cool. And I'm on board with it. It's not a Boomer telling me something.

So this idea of framing the issue within the existing patterns of cognition is an old idea that really took off in the 1950s with the advent of marketing. Who has watched *Mad Men? Mad Men* is the TV series about basically the realization that this is how you change people's minds in the marketing world.

So when you see a shampoo ad, I don't know if they still have shampoo ads, it's not-- this sodium lauryl sulfate effectively removes sebum from your hair follicles. No. It's this will make you sexy and young. Oh, it works. So--

[LAUGHTER]

--nuclear has now figured this out, too.

[LAUGHTER]

The most successful nuclear startups are marketing absurd notions of nuclear power that neither require fences nor roads, nor parking lots, nor employees, no cooling towers. Just beautiful architecture and green, beautiful amounts of green. They have realized that you can convince people by relying on number 3.

Now, you may decide that's fine, that's good, and you want to become a PR campaign person. Lots of this stuff out there. Have you seen the film *Pandora's Promise* or *Nuclear Now?* These are films that basically try to reframe nuclear power as a solution to climate change. They feature famous environmentalists waving the nuclear power flag.

They have these sympathetic, usually female commentators that are going on about how wonderful nuclear power is. They are talking passionately about how this is saving their future and their families, and they will set up these false dichotomies, saying it's nuclear or climate disaster, as if there were no alternatives.

They aren't saying anything real about what we need to do about climate change. They don't have anything to say about how climate abatement policy should be structured. They certainly do not discuss the economics of nuclear power in these movies.

They are not there to give an honest discussion of the issues. It's propaganda just like this, to make you feel good about what you're seeing. If you ask me, public relations is a life of crime. This is not about the truth. So, morally speaking, what we should be doing is trying to bring everyone, the green people and the red people, into this box.

We want them to face the possibility, whatever they believe, that they might have been wrong about nuclear energy and to reconsider the facts carefully. And once that happens, once they enter the adjudication zone, then logic and evidence can begin to eat away at these cognitive illusions that the public holds and that scientists hold.

And if that logic and evidence is legitimate, we will all come around to having the same view about nuclear power, more or less. But remember, people don't, by and large, decide to reevaluate their beliefs just because some expert goes ahead and tells them to do so.

Expert heads actually tend to polarize, talking heads tend to polarize people's views because they feel how they have to defend their side. So what we need is a process to restate this as a process of discovery, not a process of instruction. That's how you change people's minds. You let them find out for themselves.

So let's turn this around. Here you are, young and excited about nuclear power. You want to do your best to make sure it plays its appropriate role in the grand human experiment. You're a freshly minted nuclear engineer, and you're faced with a cranky and unscientific public and all of these anti-nuclear activists and skeptics. And the situation seems piled high with difficulty.

What do you do? Well, yes, it is in fact piled high with difficulty. But now you are equipped with a more nuanced understanding, I hope, equipped with a more nuanced understanding of these contentious issues around nuclear power-- issues of safety, issues of economics, and so on. And that should help you understand where people are coming from.

And you also now have this idea of how human cognition works. So can we put the two together? Let's therefore start by investigating the misperceptions that this cranky public holds about nuclear power. And then once we have a sense of where the public gets it wrong, we can then seek to identify ways that will reveal the cost of their innocent-but-incorrect views to them, and maybe help them change their mind a little bit about nuclear power.

So where does the public get it wrong? Has anybody actually checked? OK, so, yes, some people have gone and checked. There are a number of studies out there, but this study from the IAEA and OECD, it continues to be, I think, one of the best studies, because they actually ask detailed questions, not just like-- do you support nuclear power? But they tried to ask, is it safe? and issues like this.

So here's their first question. Is it possible to operate a nuclear power plant in a safe manner? Countries with nuclear power are in light gray. Countries without nuclear power are in dark gray. These are European countries. And so they don't tell you which country is which.

But just to give you, they want to show you the distribution in different countries. And lo and behold, virtually all countries have more than half the people feel that it is possible to operate nuclear power in a safe way, which suggests that actually the public is not, by and large, worried about the safety of nuclear power plants.

Here's a more recent survey from this year from Americans. And they ask, thinking about nuclear power plants that are operating now, how safe do you regard these plants on a scale of 1 to 7, where 1 means very unsafe and 7 means very safe. And the majority of people give these plants a very high safety rating.

Now, I have argued in this class that nuclear power is somewhere around the threshold of what is probably acceptably safe. Thankfully, we did not get that spent fuel pool fire at Fukushima, which would have made Fukushima look much, much worse than Chernobyl, in which case, the deaths per terawatt number that we calculated would have been a much worse number.

That number is not huge by any means. It's on the order of natural gas. It's reasonably safe. It's not excessively safe. I guess we would conclude that safety is an issue we're doing well at, but we need to maintain our vigilance. Yet, many people in the nuclear community are working hard to undermine existing safety institutions.

So there's the new executive order from the Trump administration that is limiting the amount of time that the NRC can spend reviewing the safety of these power plants, as well as cutting the number of staff available to do those safety reviews. So arguably, this is something that we really need to continue to pay attention to. It's not something the public is concerned about.

This is a problem that really experts are attuned to. So I don't think we can credibly argue that public panic about nuclear reactor safety is what's holding back nuclear power. It's an issue, but it's not what the public is worried about. And if someone tells you this is what the public is worried about, it's a straw man argument.

The second question they asked is, are you concerned with nuclear power plants being targets for terrorists? And, wow, yeah, people are really concerned with this issue. Now, we didn't really get into this issue in depth. But I'll just give you a little history here. After 9/11, where terrorists flew planes into the World Trade Center, public pressure caused the NRC to admit that a terrorist attack against a nuclear power plant was something that needed to be considered.

And the NRC responded by saying that existing plants were safe enough. The industry, if you were alive during the time-- I guess you were alive, but you weren't very old-- the industry actually said that there was no risk at all, that this would never happen, which is pretty gutsy considering that two planes had just been flown into the World Trade Center and one into the Pentagon.

Eventually, the NRC came around and said the containment buildings are not actually strong enough to withstand a direct impact from a large jumbo jet like a Boeing 777. Small planes, they were fine. But for the biggest planes, they're actually not strong enough. It's mainly actually the shaft of the engines, which, that at high speed is basically like a penetrator and it can just plow right through the containment.

So the NRC said, OK, we're talking about the AP1000. We want Westinghouse to make the containment thicker. And they did. But the NRC said-- but all the other 100 nuclear operating nuclear power plants, they don't have to do anything. Union of Concerned Scientists, which is a expert anti-nuclear group, said that's not good enough.

Why don't we do something for the existing plants? Because fixing just 2 plants out of 102 plants does not fix the problem. And I think I drew this on the board for you previously. But what they suggested was-- you have your reactor here and they said, why don't we just put up like large I-beams sticking out of the ground.

That way, when the airplane flies in, it shreds itself on these I-beams and it loses kinetic energy. And it's cheap, right? It's just like this stack of big rods around the reactor. Not that expensive. And NRC said, no, no, no, they don't need to do anything. Not a problem.

Then, China was the first country to actually buy the AP1000. And China said, we don't want to pay for all that concrete. So they thinned the containment back out to be a thin containment. So you can fly airplanes into the Chinese reactors and cause meltdowns, just not the American versions.

And then, eventually the NRC said, you know what? OK, we'll do something about this concern. What we will do is we will establish regional offices or reserves of equipment to, say, backup generators and fuel for the diesel generators and pumps.

So in the event that there is such a catastrophe, we can maintain emergency operations at the reactor. And they call this the B.5.b equipment after Section B, paragraph 5.b of the regulations. So NRC established these regional centers.

And then after Fukushima, people began to get uncomfortable about that spent fuel pool fire thing. And they said we really can't let this happen if there's an earthquake in the United States. And the NRC said, oh, remember that B.5.b stuff we did for terrorism? That will work for that problem, too, for large natural disasters.

So they decided to test run some of that stuff that had been sitting in storage for a while. And they pulled it out, and guess what? It didn't work. A lot of that equipment had never actually been operated. People had not been trained on how to use it.

There were no plans in place for how to get access to it in the event there's a large earthquake or a large hurricane or something that makes driving through the roads very difficult and so on. And the reason is that that equipment was not considered safety equipment.

So because it was not classified as safety equipment, it did not have to be routinely tested and checked. But they liked it that way because it was easier. So here's an example of where experts continuously, I would argue, get it wrong. And the public is quite concerned about something that, I would argue, isn't a crazy concern.

So the third major concern, a question that the survey asked was, are nuclear materials sufficiently protected against misuse, dirty bombs and nuclear proliferation? And in almost all countries, much less than 50%-- here's the only country, there's only a few countries above 50% here-- felt that materials were indeed adequately protected.

Now, I argued that the security of regular spent fuel, which contains plutonium, is adequate because it's highly radioactive and it would be very difficult to divert. Nevertheless, there are many nuclear engineers who want to do reprocessing and convert that self-protecting spent fuel into separated plutonium, which is what is in this can and can be carried out of the building under your armpit.

Give someone a couple hundred thousand dollars, $1 million, and said, bring me a few cans. And some person who works at the factory might actually do it. We didn't discuss this in a lot of detail, but there are actually a lot of real-world examples of this stuff happening, especially in the former Soviet Union. Lots of theft of nuclear materials, even HEU being stolen from the United States.

It's not exactly definitive, but there's reasonable evidence to suggest that the Israeli nuclear weapons program used highly enriched uranium stolen from a plant in the United States. If you have never heard of this, look up the NUMEC, N-U-M-E-C, the NUMEC affair. It's a very interesting story.

The files were sealed by the FBI, so we don't really know what happened. No one is coming clean on the affair. The linkage between nuclear power and nuclear proliferation is indeed very subtle. It is a political decision, but it's a decision that is influenced by the access to technology.

And where states want to pursue weapons, we see more often than not that they're willing to use their civil technology to do it, which is why we invented safeguards in 1950, the idea that the IAEA was going to protect civil nuclear power from this problem. Unfortunately, technological progress has made safeguards largely ineffectual for technical reasons.

So I talked about how big these enrichment plants are, these commercial plants, much bigger than the plant that you need to make a bomb. They can make bomb quantities of HEU in about a day. Now we're talking about exporting reactors that contain HALEU. It depends on who you believe. But HALEU is arguably a directly weapons-usable material.

And a single reactor contains more than enough HALEU, many designs contain more than enough HALEU to build a bomb. Are we going to export basically bomb kits to other countries? These are issues that I would argue we really need to take very seriously, because the simple single use of a nuclear weapon is going to make Chernobyl look like a beautiful day in the sunshine.

So I think we should be taking it more seriously. The public thinks we should be taking it more seriously. Somehow the nuclear export community doesn't take this very seriously. Finally, the public is pretty much split about nuclear waste. This concern doesn't actually rank as high as terrorism or nuclear proliferation, which I think is interesting.

Remember that the safety around nuclear waste is not really the concern. And I would argue that the fact that the public isn't worried about the safety of reactors means that the public is not just worried about radiation. If they were just worried about radiation, they were worried about reactors, then they would be worried about spent fuel. But we don't see that.

They're basically not worried about reactors and they're kind of moderately worried about spent fuel. So I don't know what explains this, but I will offer you a conjecture. And the conjecture is that perhaps this is really the public saying-- we want evidence that the industry is going to provide complete and responsible management of all the liabilities generated by nuclear power, preferably in our lifetime.

We don't want to see this just kick the can down the road to my children's generation. Who knows if that's what's really behind the public answers here? But I suspect that's what it is. So this is every single question that the IAEA and OECD survey covered. There are other surveys about nuclear energy, like I said, but they don't usually kind get into this granular kind of detail.

But the bottom line is this-- surprise, 3 out of 4 people are totally on board with there being more nuclear power. The number has been over 50% of the public since the year after Chernobyl. Here's Chernobyl. We had a slight dip. And then the majority of the public has always favored nuclear power.

Perhaps there are other points where the public is really off the reservation here with respect to the facts, but I can't find it. I'm trying to figure out how the public is so wrong. I don't see the evidence. You have the public mandate to do nuclear power. What nuclear needs to do is get its own house in order and make it work. This is not a public problem.

So wait a second. Who exactly is the stubborn entity here? Is it the public or is it us? Is it nuclear engineers who have difficulty facing some of the challenges that nuclear power faces? Maybe it's nuclear power and maybe nuclear engineers are really on this red line with respect to tackling these hard problems that nuclear power faces-- like, oh, we don't want to think about these things.

Ah, it's going to hurt my professional career. You, however, are now a select subset of these nuclear engineers. You have taken this class. I hope you are more attuned to these issues. And I hope that you will begin to evaluate these matters for yourself. You don't have to take my word for it. Use your skills and go out and do these calculations yourself.

Here's my proposal. What we need is for the public to hear about the benefits of nuclear power from the people that they trust-- independent scientists, people in their communities. And we need nuclear engineers to hear about the problems from the people that they trust. I've argued that familiarity and shared patterns of cognition give us a framework for that kind of credible communication. So here it is.

The final answer is-- don't shun your critics. They are, in fact, your friends. They are the people who can show you the path to salvation for nuclear power. And it's a dialogue between these two opposing groups, these expert groups, a process called dialectic, truth finding through debate, that will get us there.

AUDIENCE: I have a question. The course is [INAUDIBLE] nuclear. But this kind of objection from the public also [INAUDIBLE]. So in your opinion, does it make sense that this kind of change in the public happens in a forum rather than a conversation or talk?

R. SCOTT KEMP: In what forum?

AUDIENCE: Like in an open conversation that is in general with peers around that [INAUDIBLE] instead of having a nuclear forum.

R. SCOTT KEMP: Oh, I see. Maybe. So I think the argument here is that both advocates and skeptics are potentially wrong about certain issues, about different issues, maybe. But if you put the advocates and the skeptics in the same room, they don't necessarily speak the same language.

And so you can have these fora, but they're not usually very effectual in changing people's views. The way people's views are changed is that they have discussions with people who are close to them. So the engineers need to talk to other engineers and scientists. The lawyers need to talk to other lawyers.

The environmentalists need to talk to other environmentalists. The public needs to talk to other people in their friend community, and so on. It seems inefficient, but if enough of this happens, there is eventually communication that percolates up and down this chain. And that's actually how people's opinions change.

They have these dialogues, this dialectic in their community. So we not only have to have these conversations, we also have to be willing to do one more thing, which is to stand up to people in our own community when we disagree with them. Instead of just going with the flow, we have to say, wait a second, perhaps we are overlooking something here.

Maybe we should take this concern a little bit more seriously. And as I said, MIT is actually pretty good place for this. People in this department now do take economics seriously. It wasn't always the case or isn't always the case at other departments. Definitely not the case in a lot of industry.

But if you are willing to do this, if you are willing to be that person who's just pushes back a little bit, then you will be slowly bringing together the individuals in these communities, and both sides will very slowly have their cognitive illusions minimized. You'll be doing this for people.

And eventually, we will converge to having a shared view. This is the task of finding the future for nuclear power. This task falls to you. Thank you for taking the class. I hope it challenged your assumptions and will lay forth a life of asking good questions. Thanks very much.

[APPLAUSE]