Rationally Speaking #222: Spencer Greenberg and Seth Cottrell on "Ask a Mathematician, Ask a Physicist"

Julia: Welcome to Rationally Speaking, the podcast where we explore the borderlands between reason and nonsense. I'm your host, Julia Galef — I have two guests with me today and they're both good friends of mine.

Spencer Greenberg, who you might know because he was on a previous episode of this podcast. He's a mathematician and entrepreneur running Sparkwave. And Seth Cottrell, who is a physicist specializing in quantum information theory.

Hey guys!

Spencer: Hey, it's great to be here.

Seth: How you doing?

Julia: Let's just ... hold on. Seth, say hi.

Seth: Hey, how you doing?

Julia: And Spencer, say hi.

Spencer: Hey, it's good to be here.

Julia: Okay, so now you, audience, know what their voices sound like.

So Spencer and Seth together run a website called Ask a Mathematician, Ask a Physicist, at askamathematician.com. Guys, does anyone call it, AAMAAP?

Seth: No.

Julia: Well, I'll just blaze a trail then and call it AAMAAP during this episode.

Seth: That is the Twitter handle-

Julia: Oh, okay.

Seth: But I've only read it, not heard it.

Julia: It's just a very satisfying word to say, AAMAAP.

Seth: I think so too.

Julia: So AAMAAP has been going for over nine years now — which really astounded me, I feel very old — and you guys have answered almost 500 questions, ranging-

Spencer: Mostly Seth, to be fair.

Julia: That's true, Seth has done more than his fair share of the work, it's true.

Seth: Certainly.

Julia: So the questions, they're all over the place, they range from "what is quantum immortality" to "is it possible to eat all the ice cream in a bowl."

Seth: Oh that was a-

Julia: Yeah, that was a good one. And the website as I said is nine years old now, but just this year, I think this fall, Seth published a book called "Do Colors Exist? and Other Profound Physics Questions," which is full of some of the most entertaining and informative questions and answers from the blog.

Basically, if you have read the XKCD book "What If?", this is very much going to be up your alley. You can find it on Amazon. We'll put the link on the podcast website.

Seth: If you're looking for the ebook version, for some reason they can't put that on Amazon, you can find that-

Julia: I was looking for it.

Seth: You can find that on the Springer Shop.

Julia: Okay, we'll link to that, too. Thanks for letting me know.

Seth: Thank you.

Julia: So, guys, to start off, why don't we tell the listeners the origin story of AAMAAP. Where did this all begin?

Seth: Well, I can tackle that. It started at Burning Man. Spencer and I shared an office in math school and I think you got invited to Burning Man and were looking for a special California friend of yours to go.

So, there's this long standing tradition at Burning Man ... I'm actually not sure how many people adhere to it ... but, there's this long standing tradition of giving back to the community. Especially the first year you show up.

But we don't have ... I mean, I can't speak for Spencer ... we don't have just a hell of a lot of skills that are applicable in the middle of a salt flat. Other than just talking about our own research and science of what we're interested in. So we figured what the hell, let's do that, and got just a red bed sheet and some pieces of wood, and nailed it to the ground and then just turned that into an “Ask a Mathematician, Ask a Physicist” booth.

Honestly, I just thought it was going to be the two of us hanging out in a very small, shaded structure just kind of talking to each other for a few hours, but it really turned into a whole thing. Every year we've done it, it's turned into kind of a throng.

Julia: I assume you had to expand your tent from that first year.

Seth: We did. The first year was a little crowded, so after that we started, basically, going to barbecue supply and getting big rain canopy sort of thing.

Spencer: We never thought that many people would want to know how the universe works.

Julia: So, are those the kind of questions that people would ask? How the universe works? Because I've met Burners and they’re… all over the place.

Seth: Yeah, they really are. At one point, a large fraction of the undergraduate physics department from MIT showed up as we were setting up and asked this just bonkers question about “How do you physically solve certain NP problems” ...They said "Soap bubbles can be used to solve minimal surface problems. Are there any other physical phenomenon that solve NP type problems?"

Julia: So, a softball.

Seth: Yeah, exactly. I believe our exact answer was “We… don't know."

Julia: What's the weirdest question you got at Burning Man?

Spencer: One of my favorites was this guy who came into our tent and said "Why?" Just “why,” and we tried to respond to him, and this went on. He kept just saying "Why?", over and over again. No matter what we said.

Julia: Did you try to ask him "Why what?"

Spencer: No, we just kept trying to guess what he wanted as an answer and give him an explanation.

Seth: That was, actually, the first thing I asked him, was "Why what?". By the way, to underscore how uncomfortable and weird this was, the guy was wearing body paint and feathers and nothing else.

Julia: Well, I assumed. So what did you end up telling him?

Spencer: So, finally, I think I said to him "Nobody knows." And he was like, "That's an honest answer. Thanks," and he left.

Julia: So you set up the website after coming back from Burning Man and just started ... were you answering questions that you got at Burning Man, or did you just started taking questions from the internet?

Seth: Well, both at first. We had a fair stockpile from all of the people that stopped by the booth, so I think the first twenty or thirty posts are mostly from the booth directly. And a lot of them since have been... A hell of a lot of them trickled in from the internet. I really didn't expect anywhere near as many people to be interested in the website as there have been.

Spencer: We also did one in Union Square, as well, in New York.

Julia: Oh yeah, I remember that.

Seth: Honestly, the questions there were even weirder than they were at Burning Man.

Julia: You know, I can believe that, actually.

Seth: One woman, we had to ask her to repeat the question five times to make sure that we really understood what she was asking. What was her question? It was-

Spencer: I think it was "How did DNA start the Big Bang?"

Seth: It was "How do scientists know that DNA caused the Big Bang?", or something like that.

Julia: Wow, really laying in some premises into that question there.

Spencer: Provocative stuff.

Julia: So, how did you answer?

Spencer: I just gave it to Seth.

Julia: Yeah, yeah. Good strategy. No wonder he's answered so many more questions than you on the website.

Spencer: You're the physicist. You take this one.

Seth: You kind of have to pick that one apart. It's like "Well, not a lot of scientists think that..." or I think I started with "Where did you hear that, exactly?".

Julia: What would you say out of all the questions, including the ones submitted online, what would you say has been the most controversial question? In the sense of generating the most heated debates in the comments section, angry feedback from readers, etc?

Seth: I think it's the basic math questions.

Julia: Interesting.

Seth: People get real mad about that.

Spencer: For me, I think it was one I wrote on "What does zero to the zeroth power equal?"

Julia: And what was your answer?

Spencer: Well, I basically said zero to the zeroth power equals one, because mathematicians say so, which I think is the correct answer. But I tried to explain in detail why that's the case. And, so to kind of give you the intuition for it, why you might think that it doesn't equal one is: So, imagine you have x raised to the x power, right?

Julia: Mm-hmm.

Spencer: Well, if you think of that as like ... zero raised to any power is always zero, because zero squared is zero times zero, which is zero. Zero cubed is zero times zero times zero, which is zero.

So people have this intuition that zero to the x power, regardless of what x is, you should always get zero. Some people say zero to the zeroth power is, therefore, zero.

On the other hand, you could think of it differently, and you could say "Well, if I've x raised the zeroth power, that's always one. If I have two to the zeroth power, that's one. If I have three to the zeroth power, that's one. So zero to the zeroth power should be one. And so you can kind of have that debate.

Julia: Yeah, it's like an unstoppable force meets an immovable object.

Spencer: Exactly.

Seth: That's deep.

Julia: Kind of.

Spencer: The funny thing about it is mathematicians tend to use zero to the zeroth power equals one. I think that bothers some people: Why? How do you justify it?

But the irony is, it's sort of justified on pragmatic grounds, because it makes formulas simpler. It doesn't really matter which way you define it. You can kind of work around it either way. And that really bugs the hell out of people, because people think of math as completely precise and objective.

But, it turns out when we say x to the xth power, there's actually an ambiguity in what we mean. We think of math as totally precise, but sometimes it's not and in that case, we're actually pointing an ambiguous statement in math. That's why that question doesn't really have a fundamental answer, and you can set it to one because it makes your formulas simpler, and everything works out fine.

Julia: I can kind of see how that would be existentially horrifying to people. Kind of like finding a glitch in the matrix or something. If I pull on the thread, all the logic and sense and meaning of the universe as I understand it will start to unravel, or something like that.

Spencer: Yeah, and you see this ambiguity with, for example, integrals as well. If you write an integral, people think of an integral as the area underneath a curve. But an integral, actually, has multiple different definitions. There's a Riemann integral, there's a Lebesgue integral and they're defined differently.

When you write an integral, you are usually not really clear which one you mean, and mostly you don't worry about it because they kind of give the same answer. But what if they don't? What are you actually talking about?

Seth: Those kind of glitch in the matrix things ... I mean, as soon you tell somebody that you “can’t" do something, like you can't divide by zero, you can't have a particular answer for zero to the zeroth power… And, of course, in physics you can't go faster than light. You cannot predict when a radioactive atom will decay. That sort of thing.

These are facts. They are nailed down.

But man, do people go after each other if you just throw that out. It's like throwing meat to a pack of dogs.

Julia: Is it just like, it inspires the rebel in them, that "Oh yeah, well watch me.”?

Seth: Exactly. As soon as you tell somebody you can't do something, there's a physical law that you can't do something, it's like "Well, I'll figure out a way to do it."

Julia: I spent most of my seventh grade free time in science class trying to invent a perpetual motion machine because they told me I couldn’t. So, I would fall under this property myself.

Seth: Yeah, perpetual motion is ... yeah, exactly. I mean I totally sympathize. I spent like three years trying to figure out how to just mathematically break RSA encryption and just totally failed, but learned a hell of a lot doing it.

Julia: Wait, is that literally impossible, or is it just extremely difficult so you should treat it like it's impossible?

Seth: There's no quantum algorhythm that if we even get a computer capable of running it, will break it. In a nut shell, you have a very big number and you want to factor it into its factors. If I just give you a 50 digit number and say “All right, this is what time what?", you're kind of in a bad place.

There are a hell of a lot of people who spend a hell of a lot of time being very clever about this, and they've found special situations, but by and large it's ... there's no proof that says that it's hard, but it's hard.

Julia: That's well put. Actually, Seth, speaking of controversial questions, I was re-reading some of your posts on quantum theory this week and it seemed like the commenters got pretty angry about a lot of it. For example, just, the many worlds interpretation. They'd do this thing where they tried to shame you for promoting “post-truth.”

They would say "I'm so disappointed in you. You call yourself a physicist?".

Am I right that quantum theory seems to make people angry? And if so, why?

Seth: Yeah, it does. It does.

Julia: Said with resignation and weariness.

Seth: Well, haters gonna hate, as they say. Studying quantum physics, one of the big things it's done for me is, it's given me a lot of sympathy for people who believe completely crazy things and are absolutely convinced of it, but can't explain it to their friends.

Spencer: Because that's basically what you believe. With Quantum physics.

Seth: That's what I believe. Every once in a while I'll see somebody living here in New York. I'll see somebody walking down the street talking about the illuminati and the tin foil hats and I'll be like "Yeah, you and me both, brother."

I hesitate to say “many worlds”, because that kind of evokes an image of sliders and some episodes of Star Trek and that sort of thing and that's not ... the exact interpretation I adhere to is called Relational Quantum Physics, and it basically says ... it's basically the idea that you take the laws of Quantum Physics as established and then apply them in general. Then you ask the question, "Well, is there anything wrong with that?". And the appalling answer is there doesn't seem to be.

Julia: Wait, is this actually different from many worlds, or is it a rebranding of many worlds?

Seth: It's so similar that by and large, most people can't tell the difference. The many worlds interpretation as it's generally described is: The universe is puttering along and then there's some kind of Quantum event, whatever that means. There's some kind of event, and then suddenly the universe just pops into these different ... that's a technical term. You learned it in physics.

Julia: No, I just liked the sound effect.

Seth: It suddenly splits into these divergent branches that never meet again, and the universe from one becomes many.

That is, unfortunately, also not ... it doesn't exactly jibe with the physical laws.

I've been listening to your show and one of the things you do is you ask people if they have a recommendation for reading. Unfortunately, I don't usually, but I read a paper a couple of years ago that I was thinking, that if you have some physicists that listen, they might be jazzed about this. There's this paper called “Bell Inequality for Position and Time.”

A Bell experiment is how you demonstrate the things that are in many states. The Inequality and position in time demonstrated that not only does the universe, in some sense, end up in multiple states in the future, but you can demonstrate that it is literally in multiple states in the past.

So the idea of the universe going forward and continuously splitting, it doesn't jibe with the laws in the first place. And secondly, it doesn't really jibe with the fact that it seems to be just as split up in the past as it is in the future, if that makes sense.

Spencer: It's not like a big tree that's branching out, out, out. It's sort of always been branched, in a sense.

Seth: There are branches in the past that kind of interact to create what we see now and then there are ... so all you can really say is reality seems to be the way it is right now and anything that can happen, does. Anything that could have happened, did, leading up to this particular moment.

I get nervous saying “many worlds” because ... I don't know how much of this you're going to have to edit out ... I get nervous saying many worlds because all of this is based on actual physical desktop experiments that you can do. So, if you do the double slit experiment, you can demonstrate conclusively that a photon is going through both slits at the same time.

When you sit back and you say "Well, what does the photon experience?", the photon doesn't literally experience going through both slits — but there are two versions of the photons, each of which feels very confident that it's going through one slit and definitely not the other.

In some sense, the different versions of the photons are in different worlds, but at the same time it's all happening on your desk right now. You could point at it and say it's right there, so it doesn't seem fair to say that these are other worlds. It's just that the one world we live in is weird.

Julia: It's true that when people talk about their copies of me in other worlds or something, they are kind of implicitly imagining… far away. Unimaginably far away, there is another me or infinite mes, or something like that, which I guess you're ... what did you call your framing of the Theory Previously Known As Many Worlds? What's it called?

Seth: Well, many worlds is still around.

Julia: Okay, the Theory Known Elsewhere As Many Worlds?

Seth: Relational quantum mechanics.

Julia: And how widespread it that? Did you come up with that name?

Seth: No, no, no, it's been around since the late 90s, I think.

Julia: Oh, okay. Well, I just don't get around.

Seth: It's very fubu for quantum theorists, I suppose. It's kind of the idea that there's nothing particularly special about quantum particles. And in exactly the same way, there is nothing particularly special about the experimenters doing the experiment.

Julia: Got it.

Seth: It's not about the observer being on high influencing the particle with their observation. It's about what is the nature of the interaction between the systems.

Julia: Yeah, I really have to wonder whether that ... like, how path dependent their reception of the theories was. If we had started with that instead of with many worlds, would the acceptance by people, maybe even by physicists, have been different? I don't know.

Seth: I have no idea. You can successfully get through a couple of physics degrees and never really have to get into the nitty gritty of this stuff.

Julia: Right, yeah.

Seth: I approach it from the standpoint of kind of like, the debate between the heliocentric theory and the geocentric theory. Heliocentric theory, we go around the sun. And the geocentric theory, the earth is definitely sitting still and the planets are doing goofy, weird things.

So you look at Newton's laws and they seem to work just fine here on earth, and then you look up at the sky and you say, "Well, the planets don't seem to be following Newton's laws. They're doing loop de loops and they're being pushed along epicycles and whatnot."

And the question that you should be asking is, "All right. Assuming that Newton's laws apply in general, and assuming that everything is moving around, obeying conservation momentum and gravity and whatnot, assuming that all that is true, would you notice it? Would it feel like you're sitting still?"

And the answer is a very un-intuitive, "Yes." I think we're already orbiting the sun at, I think 30 kilometers per second, which is just ludicrously fast, but you don't notice it.

And very much ... Well, philosophically similar, you look at the laws of quantum mechanics and you say, "All right. Well what does an interaction between quantum systems look like?" And from the outside, it looks like entanglement and from the inside it looks like wave function collapse, it looks like a Copenhagen interpretation.

Julia: Cool. I like that analogy.

I have a question for both of you. It occurred to me that having both a mathematician and a physicist on the episode with me is kind of a perfect opportunity to talk about a question that's come up a couple times in the history of Rationally Speaking.

Perhaps most recently, in my episode with Sabine Hossenfelder. She's a physicist who wrote a book called “Lost in Math,” about how physicists, at least in some subfields of physics, are too prone to evaluate theories based on their beauty. Like, "Is this theory simple, is it natural?" Instead of, "What does the evidence suggest is most likely to be true?"

Do you guys have an opinion about whether mathematically beautiful theories in physics are more likely to be true?

Spencer: Yeah, I think it's a really interesting question. And the first thing I would say about it is: So, you can split people into people who believe that there's a God that made the universe and made the laws of physics, and those that think that there's no intelligent being that made them.

	If you think an intelligent being made the universe, why exactly would you think that that being would use simple laws? Why not use complex laws? God's way smarter than we are, right?
	And again, if you think that there is no intelligent being in the universe and just the universe is, again, why would you really expect the laws to be inherently simple? Like why should it be that us beings that eventually evolve will be smart enough to understand them?
	So I don't really see really strong a priori reasons to think that the laws will be super simple. But that being said, I think there are some reasons why we might find that some of our theories end up being simple and being preferable to less simple theories. And just to give one example of that, imagine that you have some phenomena that you don't realize are connected to each other. So at first you think, "Oh, there are these different things going on." But then later you eventually recognize, "Oh, wait. There all manifestations of the same phenomenon."
	So for example, it may be totally unobvious that the reason you fall down after you jump is related to the reason that the planets move in certain motions. But eventually, you kind of unify those things. And that actually can really simplify your theory a lot, rather than trying to explain everything using different ideas. So that's just one example why simplicity can appear, even if it has nothing to do with like, "Oh, the universe is fundamentally simple."
Seth:	Yeah, that's a good way to ... Yeah. That's a good way to put it. The laws of the universe, they're very holistic. All of them apply all the time, it's just that some of them kind of don't matter. Like the laws of fluid dynamics apply in deep space, there's just no fluids around for them to apply to, so we don't notice them so much.
	We wrote a post about this, and Spencer made a point, that over time it's been sinking in, just how very profound it was. I think you pointed out that the equations tend to look pretty because the ideas that we find ourselves using over and over again, being naturally lazy beings, we use more and more succinct notation for it.
Julia:	Oh, like using short words ... Like words like “and, or, the, he, or she,” they're short because we use them so often. Not the other way around. Or ... Is that a good analogy?
Seth:	Correct.
Julia:	Yeah, I didn't say it well.
Seth:	Yeah, yeah, yeah.

Julia: Hopefully you got it.

Seth: No, no, no. Yeah, exactly right. Yeah actually, exactly right. Like for example there's a mathematical operation called the determinant, that you apply to matrices, to square grids of numbers. And in some sense, it's about as complicated as it can get.

If you know somebody who's taken linear algebra recently, and you say determinant near them, they'll just huddle up into a ball and start shivering. Nobody likes to do these things.

And yet the notation is just, if it's a matrix A, it looks like absolute value of A. It's the cutest little notation in the world.

Spencer: That's a really good example. Yeah.

Seth: Yeah. And you look at say the wave equation, when you describe the philosophy behind how waves work, it kind of makes sense. Like if you imagine people playing double dutch, if you imagine the jump rope when it's up and kind of concave down, in a minute, it's gonna be pulled back downwards. And when it's at the bottom and it's concave up, it's gonna be pulled upwards in a second. And that's basically what the wave equation is.

But when you actually have to write it down using math, you're equating second derivatives with each other and then you say, "Well, what exactly do you mean by second derivatives?"

And then, some of the notation's actually, well, it's the sum of second derivatives in all three dimensions, and then pretty soon you realize that this very compact notation is really talking about a hell of a lot.

Spencer: Right. Even to just define the second derivative, you have to define in terms of the first derivative. And the first derivative you usually define in terms of limits. And stuff like, if you were to write out all of that stuff for someone who had never heard of these ideas, you're like, "Wow, that sure seems really complicated now."

Seth: Yeah.

Julia: Well-

Seth: And then ... Yeah.

Julia: There was this one aspect of beauty that Sabine was talking about, which doesn't seem captured by what you guys are talking about now. It was called “naturalness.” And the way Sabine defined it was, I'm quoting her, "A theory should not appear like it has been hand made. It should not have some conspiracies among the numbers that they've turned out to be just right.

“For example in particle physics," she said, "We have a big gap between several energy scales. One energy scale's called the Planck mass, that's a pretty large energy scale, it's about 15 orders of magnitude larger than the heaviest particles that we know, for example the Higgs boson. And that brings up the question, where does this large ratio come from? This is what we call unnatural."

And she was saying that there isn't really a good justification for using naturalness as a criterion to lean towards some theories and away from others.

And I've actually talked to some other physicists who think there is. Well, of course they do, because she was arguing against them. But I’ve now met some who do.

Seth or Spencer, do you agree with Sabine about naturalness? Because that seems to be more about the values of the coefficients in the equations, as opposed to, “How complicated does the equation seem to us?”

Spencer: Well, one thing I think you can say about that is that, sometimes we humans, we're trying to force a theory to work and so we'll like stick in the thing that just tries to make it fit. And a classic example of this would be like the epicycles, trying to model the movement of the stars when you haven't yet realized that it's better to move the center of the solar system to the sun instead of the earth, and so you're kind of putting in these awkward circles within circles within circles, to try to fit the curves.

And so sometimes there's things like that, where humans are trying to jam a theory into fitting.

And then as soon as you say, "Oh no, wait. We need to move everything to where the sun is in the center,” that, like, gets rid of all that cruft. And my understanding is that even once we move to thinking of the sun as being at the center, it still didn't quite fit because we had I think the idea of a circular orbit.

So it was still a little awkward and people we're trying to make these kind of ad hoc adjustments, and then eventually was like, "Oh, no wait. They're ellipses, elliptical orbits." And then we got rid of that cruft. So there's something there, maybe, about how humans can put awkward kluges in because the theory doesn't quite work.

Seth: Yeah, no. Yeah, I totally agree with the naturalness thing. It's kind of like if ...

Julia: Sorry, you agree that it is a good criterion?

Seth: Naturalness?

Julia: Yeah.

Seth: Yeah. Yeah. Not immediately. It helps a lot to see what's been done before, to get kind of a sense of the smell, the character of natural law. It's a little bit like reading a bad computer code. You make an error and instead of kind of stepping back and looking at the code overall you say, "Well, I'll just write a little patch for that." And then pretty soon things don't line up, so you have to write a patch for that.

And then pretty soon, to really stress the metaphor, instead of having a nice smooth blanket, you've got this quilt that's just nothing but patches all stuck together. That's software.

So yeah, when you read a description of physical law that says, "Well, I've got this idea that explains this particular thing, but it doesn't really explain anything else and I don't know why it works" — then you start to get suspicious. So like the epicycles, they really did a pretty good job of explaining the movement of the planets, but they didn't answer questions like, "What's going on? Why do they exist at all?" I think the biggest uses they have essentially kind naturalism, they're like, "Well, circles are very natural. So circles in circles."

Spencer: Of course. Sure.

Seth: But yeah. "Why were they the exact sizes they were? And why were they lined up the way they were?" Sort of thing, they didn't have answers for that.

But Newton's law of gravity, it's very just kind of, everything works like this. Not just the planets — the Cavendish experiment demonstrates it's not just planets, but rocks sitting next to each other obey the exact same laws of gravitation. So it's a simple thing that explains a hell of a lot.

I'd say that physics in the early to mid twentieth century, they started to swing wide when it came to particle physics. And they got some remarkably simple philosophies about how particles interact and how they should work. They tied in the basic ideas of quantum mechanics with relativity, got these ideas of how particles should exist and how they should interact, that was just gorgeous, just absolutely beautiful.

And they started coming out like, "You know what? I bet there are like all these particles out there and I bet they weigh this much." And then went to their particle accelerators, and dammit if they weren't exactly right.

And it has a way of causing you to become a little bit cocky about the power of math.

Julia: Spencer are you gonna take that lying down?

Spencer: Well, I don't know if that's a compliment or an insult. I'm really not sure.

Seth: Well it's, basically they ... Here's the thing, math on it's own, owes nothing to physical reality.

Spencer: Indeed. Math's not even true.

Seth: It's not like physicists are gonna go to their particle ... Like, the people at CERN are not going to suddenly discover new math. They'll discover new facts about the universe that may imply some new rules that we could write using math, but they won't be discovering the next biggest prime or something. Or they're not gonna discover a new math rule that we didn't know about.

The rules of math are, for lack of a better word, they're made up. They are exactly as made up as language. But that's not to say that they don't mean things. Like, the words that we're using right now are made up, but they still mean something.

Julia: Wait, but ... Okay. Spencer, at the beginning of the episode — let's get some reality checks on all this nonsense...

Spencer: Now we're getting really controversial here.

Julia: Yeah. Okay, so at the beginning of episode, we were talking about how zero to the zeroth power equals one, sort of by decree of mathematicians.

Spencer: Yeah. You didn't know mathematicians ... No, no, they can just declare it, yeah.

Julia: Yes, but what if different mathematicians declare different things, then what happens?

Spencer: Then they'll just argue about it forever in a series of papers or something. Or ignore each other.

Seth: So I actually ... That one did bother me. I was out, like, trying to find ...

Julia: Did that one almost cause a rift in AAMAAP?

Seth: Yeah.

Julia: I'm sorry, you were trying to find...?

Seth: I've been trying to find an example where it was used and defined to be something other than one, and I didn't.

Spencer: There you go. Zero to zero equals one, by convergence of mathematicians.

Julia: All mathematicians who disagree are disappeared!

Spencer: They're no longer mathematicians, therefore ...

Julia: They haven't been heard from since.

Seth: Way back in the day, a bunch of mathematicians got together and they decided to write down just a list of all the underpinnings of mathematics. Just so that they could all agree on what they were talking about.

And that gave rise eventually to Gödel coming along and saying, "Well ... " proving his incompleteness theorem and kind of throwing everybody under the bus, mathematically speaking. Forcing everybody to write down exactly what the axioms are. What are the basic rules? Forced them to also admit that there are kind of mathematical dialects, like whether or not you want to include the ...

Spencer: Continuum hypothesis.

Seth: Continuum hypothesis, or the Axiom of Choice. These are things that they seem to be true. They seem to work, but we can't necessarily prove them. So they're kind of thrown onto the list of axioms as ... Actually I think the axiom of choice has been proven to be impossible to prove, as well as proven to be impossible to disprove. So I think that falls pretty firmly into the axiom category.

Spencer: Yeah, and I think that's a really important point that most people don't know about math. Which is that, math started with just people trying to do things in the world. Like they're counting how many sheep there are, or something like that.

And eventually, after doing that in many different things — counting sheep, counting carrots, counting children — you start to generalize. And instead of thinking of numbers as adjectives that are referring to sheep or something like that, you start start thinking of numbers as nouns. You kind of take this flip in perspective and you say, "Oh, we can just think of there as being ‘three’ and not just three sheep, or three children, but just three. And then we can talk about what properties that they have."

So really math started as a thing that's useful, and people used it for a long time doing all sorts of things from counting to areas of plots of lands.

And then eventually after a very long time, people eventually were like, "Hey, what the heck is this thing we're trying to do? Can we put it on a firm foundation?" And that's where it really starts all going crazy.

And a lot of people think that math is on a firm foundation. They think that someone has proven that one plus one equals two.

But really, if you really get into the core of it, you start to realize, as Seth was talking about, there are these different flavors of math that depend on what axioms you choose. And mathematicians don't agree on what ... Unlike zero to zeroth power, they don't agree on what axioms to use.

And probably one of the most famous examples is the Continuum hypothesis. Which is a very, very fun kind of question which is: There are an infinite number of integers. And there's also an infinite number of real numbers. And the Continuum hypothesis is about, Is there an infinite set, does there exist any infinite set, that's bigger than the integers — in a very precise sense of being a bigger infinite set — but smaller than the real numbers? Is there an infinity between those two?

And basically, that turns out to be also independent of the axioms of math. And so you can either add it as an axiom, or you can add its opposite as an axiom, and it's totally arbitrary.

And so we could get different flavors of math, and there's no way to decide between them except to say, "Well, if you like a more complex, interesting math, then you go one way."

Julia: It's aesthetic?

Spencer: Yeah. "Or you want a tidier, cleaner math you go the other way."

Julia: Where do you land?

Spencer: What sort of math do you like, Julia?

Julia: I don't know. I'm confused and alarmed by the question. Where do you land?

Spencer: I don't have an opinion because it's never come up in any actual problem I wanted to solve.

Julia: Well, it's coming up now!

Spencer: It didn't matter. No, but I think it's really interesting to think about, "Well, what is math really?" And I agree with Seth that math is a language but it's different than most other languages because it's extremely precise and I think of it as a language of patterns.

So, it's a language we invented that allows you to describe, sort of, any type of pattern — at least that we know how to describe — can be described with math. And so it's not that crazy to say, "Well, okay. Then it's less about kind of math being this thing that is inherently provable and defensible, and more about, it's this thing that allows us to do all these different things by describing sort of any sort of pattern we come across."

Seth: Yeah, it becomes very frustrating. We get a lot of people writing in who have figured out a "Theory of everything," or have figured out all of math, sort of thing. By and large they haven't.

Julia: Shocker.

Seth: But ... Yeah. They get-

Julia: I have a question. Which one of you gets weirder mail? I know mathematicians and physicists who are at all in the public eye tend to get weird mail. Which of you —

Spencer: Well, now Seth runs the site so he gets all the weird mail. But I would say I think the physics mail tends to be weirder than the math mail, wouldn't you say Seth?

Seth: By and large, by and large. Honestly, it's a lot of the same people will be sending a lot of theories on both. We've got a lot of polymaths, in that sense.

We'll get people who write in and have like a very particular idea about like, "Oh, I've figured out how to divide by zero," or something like that.

And it's very frustrating for them when I come back with like, "All right. So do it, that's fine."

Julia: You're like, "No skin off my nose!"

Seth: Yeah. Honestly, because it's like, you got a chess board and somebody says, "Well, I wanna play checkers," you go, "Well, that's fine. Go ahead and play checkers."

When you ask and answer questions about math, you're always talking about, these are the big ideas that we've all agreed upon. Two is bigger than one. There are numbers in between one and two, that sort of thing.

These are axioms that we've made up. If you disagree with them, it's not explicitly that you're wrong. You may be self contradictory and therefore wrong, but it means that you're not playing the same game as everybody else. But you may not necessarily be incorrect.

Spencer: Right. People sometimes get bugged out when you do things like, you make up a new operator. You're like, "I'm defining a new operator called 'plus.' It's not the same as the plus operator you know, and it has the power that one plus one equals one, and so on," and people are like, "Whoa, what are you talking about?"

You're like, "No, no, no, this is a ... Math is a language and we can define things the way we want. I can have this plus operator that has these different properties."

Actually, some mathematicians have done funny things like this where they'll redefine addition, multiplication, exponents, and so on, and then they try to redo the theories of math in this new weird world where all the operators mean different things. They can actually create ...

Julia: How interesting.

Spencer: ... these kind of very interesting, beautiful, consistent theories that are really kind of cool.

Julia: Is there a use for that, or is that just like a fun party trick?

Spencer: Sometimes there is a use. Because the way I think about applied math is basically: you look around the world and you notice patterns and you notice repeated elements. Then you go back and you say, "Can we describe these patterns with math," and you write down the math to try to describe them.

Once you've done that, what's cool then is you can just forget about the world for a while, and just look at the math, and study what properties it has, and derive things about the math that you didn't know before.

Later, once you've done that, you can take those new things you've learned about the math, and go make predictions about the world, and check the world. And you will often find that oh, wait, the world has that property that I predicted it would because I correctly found this pattern — and this pattern, according to the math, implied these other things.

Insofar as you can find parts of the world that correspond, just like the way you can find parts of the world that correspond to the regular "plus" operator — like I take three balls, put them in a bag, I add two balls to the bag, now I have five — you can find things in the world that also correspond to some other kinds of weirder operators, that are pseudo-addition operators or whatever. Then that math will describe those parts of the world, right?

Julia: I can see, however, how it would be maddening to a certain kind of person to be told, "Yes, you're completely correct — in your own math."

Seth: Yeah, nobody likes it. Everybody hates it. We really, we do really have this ... Because there are things that you can say about the universe that are hard and fast and definitely true. You may have different ways of describing them. You may have different ways of writing them out, but they are definitely true. They are facts.

In math, it really is a language. It is up in the air what you decide to use or not use.

Spencer: That being said, there are some constraints. If you have inconsistencies, your whole system will fall apart and it won't be useful —

Julia: Can't you just invent a new math in which inconsistency is allowed?

Spencer: Well, you could do that. You can have inconsistent math. It's like, look, I'm not going to deprive anyone of their inconsistent math, but the problem is you just get ...

Julia: “In your own math, Julia.”

Spencer: You just get a very uninteresting, boring thing where you can prove any statement. It's pretty ... yeah.

Seth: We actually had somebody show up at the booth — pretty young, I think they were like 15 years old — came up and they were like, "I want to break math. What if five was equal to zero?"

I was like, "Well, that's fine. That's modular arithmetic." We got into this whole thing about how incredibly useful modular arithmetic is. And they were so excited. It was like, "I tried to break math — and it just kept going!”

Julia: Oh, that's so sweet. I was worried he'd be mad, because he wanted something to rebel against and you just deprived him.

Seth: No, most people have pretty good humor.

Julia: That's a much sweeter ending.

Spencer: One thing that's funny, I've observed that when people want to challenge physics or challenge math, and have their own theory — which, I think a surprising number of people want to rebel against it — is that almost always, the theories they come up with are less weird than the reality.

Which, may be the universe is more creative than humans are, I don't know. But you think about relativity, a lot of people who come up with their own theories, they want to say, "Oh, no, Einstein was wrong" — and then they have this theory that's way more normal and plausible-sounding than relativity. It just happens to be totally untrue, and relativity happens to be right.

Relativity is really bonkers, like really bizarre, saying that space and time are not objective and can be warped by motion and so on. Similarly, look at quantum mechanics. Quantum mechanics is even crazier, like the ravings of a madman, but it just happens to be true.

Seth: I think it was Michio Kaku who said, “The only thing that quantum mechanics has going for it is that it works.”

Julia: Literally the only thing.

Seth: Yeah.

Julia: I have time for maybe one more question, and I think I want to use it to ask Seth about something in one of his posts.

So, I think this was one of the posts on quantum entanglement. And in that post, you tell this fascinating story of how some fringe parapsychologists proposed an experiment using entanglement, that ended up changing physics.

They were called the Fundamental Fysiks Group, but it was spelled weird. Do you know what I'm talking about?

Seth: Oh, yeah, the Fundamental Fysiks Group.

Julia: Yeah, do you remember that story well enough to recount it to our audience?

Seth: Fred Alan Wolf and... Maybe. They've come up a number of times... Oh, no, oh God, yes, no, I do know! Sorry.

So, if you ever read about entanglement in popular media, there's a very common refrain that goes along with it: Entangled particles — parentheses, entangled particles are particles where if you do something to one, it instantly affects the other even if it's on the other side of the universe...

And to be absolutely clear: No. In no way whatsoever.

Entanglement is a rock-like correlation. If Spencer had set up a pair of quarters, put them into sealed envelopes and given one to each of us and assured us — and he can be trusted — and assured us that they are both either heads up or both tails up, then we could go to opposite sides of the universes, and if I had looked at my coin, I would know what your coin was, no matter how far away it is, but I'm not actually influencing it.

Julia: Right.

Seth: If you understand correlation that way, then you understand about 80 or 90% of what's going on in entanglement. There are subtleties because it's quantum mechanics and it's subtle, or whatever, but that's the big idea. The correlation is really the more important piece of it.

Anyway, these guys, they ...

Julia: And who are these guys?

Seth: They took a lot of acid. The Fundamental Fysiks Group.

Julia: Ah, I found the spelling of Fysiks. It's spelled F-Y-S-I-K-S, Fundamental Fysiks Group, just for context.

Spencer: Great way to be taken seriously.

Julia: Right, yeah, totally.

Seth: By the way, in all seriousness, if you're going to do a Google search for them, also do an image search just to get a sense.

Julia: I didn't do that. I'm going to have to do that.

Seth: You really should. Those guys were a whole thing.

Anyway, they had this whole idea. They were not slouches. They were actual, genuine ... Well, they still are actual, genuine physicists. They just, like a lot of physicists, they were wrong about some stuff.

They set out this idea for how to communicate faster than light. And it was: all right, you and somebody else get a pair of entangled particles. Then both of you copy them a bunch. Then you do different measurements. And if you do your measurement this way, the guy on the other end will have to do their measurement this way.

It's subtle, but it would have worked. It would have allowed people to communicate at any speed over any distance. On a cursory read through, it's not obvious what is wrong with that.

And yet, at the same time, relativity and the basic structure of the universe has some things to say about that. For example, if you're communicating faster than light, it turns out that you should also be able to communicate back in time. This kind of raised some red flags.

Anyway, it actually, it was reasonable enough that, unlike a lot of bonkers theories, it actually caught the attention of some physicists that knew what they were doing. And they combed through very carefully and found a couple of the assumptions that they had made, one of which was that you can copy your particles and then measure them. It was that copying stage that it turns out can't be done. That then became the "No cloning" theorem.

Julia: That's subtle.

Seth: It's very subtle. It's very subtle, and these guys, by kicking over anthills and coming up with these wild theories, actually helped to advance the science. Through no fault of their own.

Julia: Wow, so it was like an accidental reductio ad absurdum of some of these physics assumptions.

Seth: Yeah.

Julia: It's kind of like the Big Bang or Schrödinger's cat, which were attempted reductio ad absurdums, right, but turned out to actually work. Except the opposite, I guess.

Seth: Yeah, Schrödinger's cat — Schrödinger came up with the story of it literally to underscore how completely insane quantum physics is, and how it can't possibly work like that. Everybody laughed about it. Then pretty soon the '90s rolled around and we started being able to actually do these physical experiments and test them out. Pretty soon, the story became, "Well, maybe Schrödinger was serious."

Julia: Was he alive when it became clear that his bonkers thought experiment was actually possible?

Seth: I don't think so.

Julia: Too bad.

Seth: In the early age of quantum mechanics, like the early '30s or so when Schrödinger and Bohr and all them were running around, they were getting some subtle hints from the mathematics that things need to be in multiple states. They were all classical physicists so they were all used to this idea, maybe you don't know what's going on, but there something is going on. Before we look at the coins, we don't know if it's heads or tails but it is one or the other. We just don't happen to know.

It wasn't until, I think, 1964 that the first proofs came out that said that, no, the results of these quantum experiments are literally incompatible with the assumption that things are in a definite state. Those were the Bell tests. I don't think Schrödinger lived to see that.

Julia: Too bad. I would have loved some reaction shots.

Before we wrap up — Seth, you've already anticipated my question at the end, and answered it. I was going to ask about a work that has influenced you or changed your thinking about something. What was the name of the book that you mentioned? Or was it an article...

Seth: It's a paper. It's the Franson experiment, and it was "A Bell Inequality in Position and Time." That'll be exciting for physicists. Physicists, if you're listening... don't get intimidated by it. It's an interesting paper.

For anybody else, I've been reading through Origin of the Species and just enjoying the hell out of it. Darwin really thought about this stuff a lot and did a really good job of anticipating people's arguments against evolution. Everything I've ever heard, every remotely cogent argument I've every heard against evolution, he addresses. The guy really had this stuff nailed down.

He's a little wordy. He's a little name dropping. And he's super into pigeons, but...

Julia: Oh, come on. Physicists are super into cats, so I don't think we can really fault him.

Seth: That's fair. Anyway, Origin of the Species. It's good.

Spencer: Seth did write an article about what happens if you ... "Can you do the Double Slit Experiment with a cat cannon?" so...

Julia: Yeah, if you fire cats instead of —

Seth: I think that was your question, wasn't it Julia?

Julia: No. Was it? Hm, maybe it arose out of a drunken night of speculation and it's disappeared from my mind. As you say that, it starts to sound vaguely familiar, like it's a thing I once asked you about... I had no memory of that. I can't believe it's actually my fault after all these years! It's so full of bad cat puns. Now I feel bad.

Seth: It's in the book, by the way.

Julia: Oh, excellent.

Seth: Yeah, it turned into a great discussion of the Double Slit Experiment, the very basic math behind it... and kind of like why you don't notice quantum effects on the scale we are.

I think it turns out that if you were to do it with actual cats, even assuming low mass cats which is to say kittens, you'd need an apparatus that's something like 300 quadrillion light years long, which is just a hell of a lot bigger than the universe.

Julia: It's pretty long, yeah, pretty long.

Seth: Yeah.

Julia: Before I let Spencer answer the question about a resource that influenced his thinking, I just want to note that while physicists may be obsessed with cats, it has been my experience that mathematicians — particular this mathematician, is obsessed with ducks.

Because every thought experiment that he gives me, it seems, involves ducks. The example that I think I shared on Twitter recently was ... I even forget what the original topic of conversation was. It was something abstract that he was trying to explain to me, and I didn't understand it.

So I said, "Can you just give me a real world example of this, Spencer?"

He said, "Sure," and he thought for a minute, and then he said, "Okay, so, imagine you have an infinite number of boxes with ducks in them..."

I was like, "This is your real world example, Spencer??"

So Spencer, now that I've outed you as being obsessed with ducks, what book or resource would you name as something that's influenced your thinking?

Spencer: Unfortunately I don't have any duck related books to recommend.

Julia: That would have been so great. If your pick was duck related I would have been so vindicated. What have you got?

Spencer: Well, one book I think is really cool — it's not an easy book, but it's just cool and interesting, is this book called The Discoveries, where each chapter is about a great discovery in science. What makes it so cool is they actually have a part of the original paper that proved the thing.

Julia: Oh, nice.

Spencer: You can actually, after you read the chapter and learn a little bit about it, you can then go peek at the original paper, an excerpt of the original paper, and read what the original scientists wrote. I just think it's so neat to see how it was first presented, Einstein presenting his theory and so on. So just a fun thing to peruse.

Julia: That's really great because I, unless I'm really comfortable with a field, I usually don't want to just go straight to the primary source. But then when I'm reading the secondary source, I'm always wondering what am I missing. So it's a nice "have your cake and eat it too" kind of thing.

Spencer: It's a rare glimpse into the original science, but in a way that's a bit more accessible than trying to go read the original paper.

Julia: Yeah, exactly. Well, I guess we unfortunately have to wrap up, but this has been a blast. It's so great to have you guys on the show after all these years.

Seth: Yeah, it was good to talk to you again.

Spencer: Thanks so much for having us.

Julia: I want to put in one more plug for Seth's book, "Do Colors Exist?" You can order it on Amazon in time for the holidays. It's full of fascinating and informative questions like the ones that we've been talking about today.

Just to give you a peek, I looked at the table of contents and it's divided into four sections — I love this, Seth — the sections are, Big Things, Small Things, In-between things, and Not Things. Strongly recommended.

And also make sure to check out AskAMathemetician.com for lots more questions and answers.

This concludes another episode of Rationally Speaking. Join us next time for more explorations on the border lands between reason and nonsense.