# Abstract Mathematology with Dr. Ologist
# Ologies Podcast
# Month 1, 2023

Oh hey, it's quite frankly the episode that you never thought you'd click on and it's the one that I never thought I would do because mathematics, it's an ics, it's not an ology. But over the years, you all have begged me to cover this, I swear, and I found an ology suitable and an ologist who is going to get us emotional about numbers. Believe it! And also, non-numbers. Come on a journey, take this VIP pass, come slip behind the curtain backstage for a more intimate, chill hang with a topic that maybe has seemed a little out of reach, a little intimidating. You're about to meet the really charming and artsy side of math.

So, this ologist, of course, is a professional math-er and author and a speaker who holds a PhD in pure mathematics from the University of Cambridge and taught at the University of Cambridge, Chicago, and Nice. She won tenure in pure mathematics at the University of Sheffield in the UK, has appeared on late-night shows hyping people up about math, has given TED Talks, and written several books on the topic such as *How to Bake Pi* and her latest one, *Is Math Real: How Simple Questions Lead us to Mathematics Deepest Truths*. She's one of us and the best person possible to talk about this topic. So, she jumped on a mic from the Midwest where she's currently the scientist in residence at the School of the Art Institute of Chicago and she's also a concert pianist. You're just going to love her.

But first, thank you to patrons at Patreon.com/Ologies for submitting your questions, you can join for a buck a month. Thank you to everyone wearing *Ologies* merch from OlogiesMerch.com. Heads up, if you were hoping to play this episode for your kids, this is not an all-ages episode, but we do have many of those, they're called *Smologies,* and you'll find them at the link in the show notes. Thank you also to everyone who leaves a review because you know I look at them with my eyes so I can say one with my mouth. This one was left this week by Minecraft Girl215837 who wrote:

> *I listen to you every day and you are so good but can you make a cookie one?*

Minecraft Girl215837, first of all, that's an appropriate number of numbers in your name. Also, we do discuss cookies, so you have no idea how appropriate that is.

So, let's get into it, Mathematology. Nobody write me and balk at this. So many people have used this word, it's in the air and the universe, we're going for it. Also, fun that the word 'math' stems from a root meaning simply, to learn. So, come along with me, let me hold your hand and guide you to the wings of academia, the behind-the-scenes of a topic you did not know you could adore like this as I hear about Fibonacci sequences, Golden ratios, Common Core, loving thy neighbor, slide rules versus calculators, imaginary numbers, the nature of zero, infinite cookies, fingers, toes, knuckles, how math will change your relationships, how math is not just numbers but dare I say a lifestyle, and how math is weirder and more artsy than you think, and more with author and mathematician and mathematologist, Dr. Eugenia Cheng.

---

**Eugenia:** I am Eugenia Chang and I use she/her.

**Alie:** And you are a pure mathematician?

**Eugenia:** That's right.

**Alie:** And an abstract mathematician?

**Eugenia:** Yes! It's kind of the same thing. I mean, maybe one is more specific than the other.

**Alie:** Which one is more specific?

**Eugenia:** That's a great question! You know, I haven't thought about this. I think that pure mathematics is more the name that it gets given to distinguish it from applied mathematics in formal contexts like in university departments and in funding bodies. I call it abstract mathematics because I think pure sounds a bit judgmental. [*"It's pure."*]

**Alie:** [*laughs*] It kind of does. It kind of implies that there's an impure mathematics which seems, like, illogical right?

**Eugenia:** Exactly. And I think that there have been enough people looking down their noses at other people over mathematics that we can do with getting rid of any of those things wherever we can.

**Alie:** Yeah, it does seem antithetical to your whole mission which is to make people appreciate and get over their math phobia, right?

**Eugenia:** Or invite them to.

**Alie:** Mm-hm, invite them. Yes. [*laughs*] That's a good distinction.

**Aside:** Okay, quick aside, what is the difference between different types of math? What makes one kind of math abstract versus applied if you apply abstract to applied math? How abstract is abstract?

**Eugenia:** It's one of those things where the boundary isn't very clear cut, but the general idea is that abstract mathematics is trying to understand things from the point of view of uncovering logical structures and exploring how things fit together for their own sake whereas applied mathematics is much more about looking at problems in the concrete world around us and coming up with theories to help us understand those specific problems. So, applied mathematics is closer to physics because physics is *really* about understanding the physical world around us. But applied mathematics uses the techniques that pure mathematicians come up with often, but they are really specifically trying to solve things in the concrete world. Sometimes people say "real world", but I don't like that either because what's real anyway? Are we real? Is anything real? I suppose that's what the entirety of my book is.

**Alie:** [*laughs*] I don't know! Is math real?

**Eugenia:** Is math real? Am I real?

**Alie:** Nobody knows! One thing that I love about your book is just that it's one of those questions that we're all afraid to ask. I think some very intrepid TikTok-er was doing a Get Ready With Me video and was like, how do we even know math is real? And I think a year or two ago, it shook the world.

[*clip from @gracie.ham's viral TikTok video*]

*I was just doing my makeup for work, and I just wanted to tell you guys about how I don't think math is real. I know that, like, it's real because we all, like, learn it in school or whatever but who came up with this concept? I know you're gonna be like, "Pythagoras!" But... How?! Like, he didn't even have plumbing and he was, like, "Let me worry about y=mx+b." Which, first of all, how would you even figure that out? How would you, like, start on the concept of algebra? Like, what did you need it for?*

Do you remember that video?

**Eugenia:** Yeah, and you know that was one of the things that inspired me to write this book because I replied to her. [*Alie exclaims*] I wrote a document, and I just stuck it on my webpage, and I just replied to

each of her questions. Then I did a few radio interviews because people picked up on the fact that I'd replied to all her questions and people emailed me from all over the world saying, "Oh my goodness! I've wanted to ask those questions all my life and I thought I was stupid, and this is the first time I've thought that maybe I'm not stupid!" Or "I thought I was intelligent in every other way except this and I'm sitting in my car crying because you've finally validated me after all these years." And I thought, wow, this has really, really tapped into something that has hit people all around the world and it's really affected all these grown adults including grown men emailing to say that they were weeping in their cars because I had finally validated their questions after all these years, people who thought of themselves as otherwise intelligent. So, I thought, maybe I'll write a whole book about this.

**Alie:** And so, did that spark the book? Did you email your book agent and say, "Listen, I already started on a doc here. We got something here."

**Eugenia:** Yeah, I already had thoughts about the questions that people always wanted to ask. I've been teaching art students at the School of the Art Institute for some years now and quite often, what we do is like therapy for their past math trauma and they tell me all the things that went wrong and all the ways in which they were made to feel stupid and the burning questions they had that never got answered because they were told, "That's a stupid question," or "You're not supposed to ask that question. You're supposed to answer the questions that *I* tell *you*." So, I'd already been building up a catalog of questions that people have really wanted to ask and that they never get answered. And then when that happened, I thought, maybe there is scope for this as a whole book.

**Alie:** Was part of that math trauma, Math Barbie? Do you remember, "Math class is tough."? Do you remember that one? [*giggles*]

**Eugenia:** Oh no! I mean, Barbie is very topical at the moment, isn't it? [*Alie laughs*] [*Math Barbie says, "Do you have a crush on anyone? Math class is tough!"*]

**Aside:** Boy howdy, okay so this Teen Talk Barbie came out in 1993 and rightly enraged female scientists and mathematicians and really any human with a brain who thought that sexism was weird and that children get brainwashed into gender stereotypes. So, there's one guerilla group calling themselves the Barbie Liberation Organization and they bought a bunch of Teen Talk Barbies and talking GI Joe dolls and they swapped their voice boxes so that Barbie said things like, "Troops, attack!" and made machine gun noises and GI Joe said, "Let's go shopping." They did this in December of that year and a lot of kids and parents were surprised on Christmas morning to have a tiny man in combat fatigues lamenting that [*"Math class is tough!"*].

**Eugenia:** I do not remember that one but there was a spoof that appeared a few years ago in my research field. My research field is Category theory which is considered to be one of the most abstract parts of mathematics and even abstract mathematicians sometimes think it's too abstract. So, there was this whole series of Barbie cartoons where Ken would say things like, "Oh my goodness, what even is a monad?" And then Barbie would just go, "Well, obviously it's just a monoid in the category of endofunctors." [*Alie laughs*]

**Aside:** Okay, PS for context, this comic was part of a meme known as Feminist Hacker Barbie which arose in 2014 like a phoenix from the firebombed ashes of a Mattel book called, *Barbie: I Can be a Computer Engineer* which was marketed toward children and featured a teen Barbie learning to computer. It involved illustrations of Barbie at a laptop and in class and it was captioned with passages such as, "I'm only creating the design ideas," Barbie says, laughing, "I'll need Steven's and Ryan's help to turn it into a real game." Naturally, computer people, some of whom were known as women, did not enjoy the existence of this book. So, one of them, Kathleen Tuite, created a meme

generator that spawned so many realistic and really sardonic takes on Feminist Hacker Barbie. You can read more about it in an article titled, "Barbie Fucks It Up Again."

So, when Barbie explains to her male classmates that "A monad is just a monoid in the category of endofunctors," it's a definition so legendarily opaque that it's become a math and programming joke itself. But if you'd like to know, a monad in math is an algebraic structure and in programming, it's used to structure computations as a sequence of steps. A monad can be a thing that describes how something is supposed to be modified but it isn't really a thing. The etymology of monad even means "Everything or nothing at all." So, if it's confusing, that's the joke. So, now we get the joke.

**Alie:** If you're seated next to someone at a dinner party and they were to turn to you and say, "Is math real? Who invented it and how do we trust it?" How do you begin, in a short interaction, to get them to trust that math *is* real or at least look at it in a different way?

**Eugenia:** Well, first I would validate their question. Often when they're asking those questions, they're already full of doubt, skepticism, and past trauma. Sometimes they're trying to say, "None of this is real, it's all a load of... books," can't say any of those words out loud... [ *"Yes, you can."*] It's all a load of codswallop, it's all a load of codswallop. [*"codswallop" repeated in slow motion*]

**Alie:** [*chuckles*] Okay.

**Eugenia:** That's often the subtext of their question. Sometimes it's because, especially in a dinner party situation, they may feel intimidated by finding out I'm a mathematician and unfortunately that happens a lot especially because I'm not a male person, I'm not a white person, and I'm not necessarily how people expect a mathematician to be, whatever that is. So, quite often, people feel intimidated. So, it depends where those questions are coming from.

I also say, what does real even mean? And spoiler alert, from my book, I don't actually say, "Math is real," nor do I say, "Math is not real." What's really more of a point is, how does it help us? It doesn't matter whether something is real or not, really, if it helps us in some way. That's what I think in the end. So, then the question is, does math help us? And does it help us in some way that you, the person answering the question, cares about because people might say, "Sure, people can use math to fly planes and make computers work but that doesn't mean that *I* have to care about it." So, then I try and find out what they care about themselves and whether they care about thinking clearly about the world around them.

**Aside:** Do you surf, or eat, or paint, or eat paint, or golf, or wear clothes? Math is in the tides, it's in the temperature gauges in your oven, putting angles, Rubik's Cubes, hair braids, fabric knits, and lasagna yields. So, we all have stuff that gives us butterflies, just nauseated with happiness. And there's a shitload of friendly, and helpful, and benign, and dazzling math involved.

**Eugenia:** And depending on where the person is coming from, when I say that math helps me empathize with other people, that can be really mind-blowing because that is not something that is often presented in math class, I think.

**Alie:** Yeah, how does it help you empathize?

**Eugenia:** There are two ways I think. First of all, it's a technique for understanding how arguments are structured. If I want to try and understand somebody who has a completely opposed point of view from mine, then I can do it by understanding where their argument is coming from. Because it's always coming from somewhere and it's never going to help if we just sit there and go, "Oh, that person is just not being logical." Their point of view has come from somewhere and one way to empathize with other people is to understand where their point of view has come from.

**Aside:** So, being in a math mindset primes your brain for taking something complex and going a step back and breaking it down through logic. How does one get from there to here?

**Eugenia:** It doesn't mean that we're supporting it and it doesn't mean that we're claiming it's good but we're just understanding where it came from, from *their* point of view.

Abstract mathematics also helps because it's a process of seeing patterns and making analogies between different situations. So, at a basic level, if you say, "Two plus three equals five," what you're really saying is that anytime you take two objects and another three objects, as long as they don't spontaneously combust or coalesce, you will end up with five objects. And that's a pattern that when we teach arithmetic to small children, we show them doing that with physical objects over and over again until they see the pattern forming in front of their eyes. And that's really a way, I think, to access empathy with people who have differing opinions from us because it's about finding an analogy between our situation and theirs.

**Aside:** So, between you and the guy who just flipped you off in the Trader Joe's parking lot, there must be a common denominator.

**Eugenia:** So, it can be quite a far-fetched analogy but because abstract mathematics is really about seeing deep patterns where the surface looks *completely* different but if you strip away enough details you get down to something that's the same underneath, I can do that with people who I really disagree with by stripping away so many details and finding some kind of analogy, even if the topic is completely different, thinking about some situation in which I have experienced something that is even remotely, abstractly similar.

So, perhaps where everybody is disagreeing with me about something and getting angry with me for thinking something and it's not going to help me change my mind. So, for example, if we think about people who don't believe in vaccines and all the ways people get angry with them to try and get them to believe in vaccines. And then if I think about a situation where a lot of people are getting angry with me and want me to believe something, then I can see that that isn't going to help me change my mind. So, that kind of abstraction and analogy helps me understand why people take positions that they take.

**Aside:** On that note, and stay with me, there was something about this chat and Eugenia's book that reminded me of therapy, of cognitive behavioral therapy.

**Alie:** It was funny because I was reading your book thinking about how much math must give you kind of an edge into understanding your own brain and other people's brains by saying, "Okay, everybody hates me, no one is texting me back today!" Is that true? Does everyone hate you? What's the logic to that?

**Eugenia:** "What is my reason for thinking this?" Exactly. And the thing is that I absolutely don't always use logic over feelings, I actually do the opposite. I always observe that feelings are correct. That's it. Feelings are always true as a basic starting point but sometimes there are other things going on as well. So, I've noticed for myself, for example, sometimes when I'm feeling terrible because some bad things have happened to me and I think about them too much, they go around my head and then I feel terrible. Sometimes I think to myself, I know intellectually, [*mutters*] because I have done cognitive behavioral therapy, I know that if I just go to bed I will feel better in the morning. And you know what happens after that? I don't want to do it because I don't want to just go to sleep and feel better in the morning. So, then I might say, well, that's not logical. But then I think no, that is a *true* feeling, I truly feel this. Okay, why am I feeling this? And then I realize, it's because it seemed like cheating. [*Alie laughs*] Then it will feel like my feelings aren't being validated if I can just go to sleep and they'll go away.

**Alie:** [*Alie laughs*] That's so true. You're also a musician too.

**Eugenia:** Yes.

**Alie:** I think we know that there's a lot of math in music but is there a lot of emotion in math?

**Eugenia:** There's *tons* of emotion in math. That's such an interesting question. I feel things so deeply when I am doing and seeing and experiencing math. And I try to write that into my books because, on the one hand, the power and the strength of math comes from the fact that it doesn't have emotions in the actual argument of it. It doesn't depend on emotions; it shouldn't depend on emotions at all to build the argument. But humans are emotional creatures and so when we're communicating math, if we don't communicate it with emotions then I don't think anything gets through, or at least much less gets through and I think that's one of the big problems with teaching and learning math. There's the idea that math shouldn't have any emotions in it, which is true, but at the same time, all human experiences have emotions in and if we try to teach someone without showing the emotional side or without giving them an emotional connection to it, then I just don't think it goes in as deeply.

**Aside:** So, there are many papers on this, but a fresh 2023 study called, "Emotions and motivation in mathematics education: Where we are today and where we need to go," stated that "Female students' enjoyment of and interest in fashion was found to result in lower engagement in mathematics and prevent them from solving word problems." And I was like, "Hold up, what?! That seems weird." So, I checked out the 1994 study they cited titled, "When Do Girls Prefer Football to Fashion? An analysis of female underachievement in relation to "realistic" mathematic contexts," and what that study was actually looking at was the tendency for contextual problems in math lessons to make no fucking practical sense at all. Like, you're given this long, fictional scenario which you'd approach from an entirely different perspective in real life.

The fashion problem in the actual 1994 study was that girls scored lower on the fashion design math calculation than one about football or just an abstract question because the fashion problem made no sense! Like, in order to divide hours of labor in a mathematically sound way, which is what the problem was about, you'd have to deliver the finished dresses before you sewed them, and this 1994 study concluded that "Two-thirds of girls used their common sense as well as their mathematical knowledge and then were penalized for doing so."

Anyway, there was actually more engagement in the problem, but the problem only made sense on a math test, not in the real world. Research has also shown that figuring out solutions to hands-on, actual scenarios gets us more engaged in finding the solution, so it's actually a two-pronged approach to make people actually care. And yes, folks are quick to penalize others without realizing that hey, they're actually asking really good, important questions and the problem is more complex in that the emperor, wait a second, is very naked. Why am I seeing his bare buttocks?

**Eugenia:** Let me put it this way. If you do have an emotional experience when you're doing something, you will remember it more deeply. So, I try to talk about things, first of all, talk about how I feel about mathematics. Secondly, I encourage my students and my readers to have feelings about it and I try to link it to topics that they already have feelings about because if I'm talking about why one plus one equals two, someone may have no feelings about that apart from horror when they remember their math lessons from school. [*"All right, pencils down."*]

But then if I can find something else, like my wonderful students who came up with thinking about when you mix paints together. When you mix one color of paint with one color of paint, you actually don't get two because you get a new color of paint. Maybe mixing paint is something that

some people have much more feeling about. Or, if you're making cookies and you've got all the dough and you decide you're going to make one bigger one instead of two small ones, you take two bits of dough and you stick them together and you make a bigger cookie. That may be something that someone can have a feeling about rather than it just being some abstract concept. So, the power of abstract mathematics is that it does not involve emotions but that also makes it difficult to learn and understand.

**Alie:** Well, how does an abstract mathematician deal with those balls of cookie dough? [*starts to laugh*] What's the answer? [*Eugenia laughs*] That's going to trouble me my whole life!

**Eugenia:** Well, it depends. In one way, if you take two balls of cookie dough, you get two balls of cookie dough. So, you take one ball, and you take one ball, and that's two. But there's another thing you can do which is smush them together and get one bigger one in which case you've kind of done one plus one equals one bigger one. And those are two scenarios that are both real. So, it's not that one plus one always equals two, it's under what circumstances does one plus one equal two? And that's where we get to the whole, ah, as long as we don't smush things together and we don't eat the cookie dough because cookie dough is delicious.

**Aside:** So, in her book *Beyond Infinity*: *An Expedition to the Outer Limits of Mathematics,* Eugenia also stares infinity right in the mouth while discussing dividing cookies for all eternity. So many cookies man, hell yeah. Yum, yum, yum, yum, yum. Right on.

**Alie:** Where in the brain is math coming from? And why, when I am stoned, do I think I understand math better? [*laughs*]

**Eugenia:** [*laughs*] I cannot possibly address that last question, I have absolutely no experience of that whatsoever and that is for real. However, there's a popular idea that math is on one side of the brain. The whole left-right brain thing I think has been mostly completely debunked. But I remember, it was actually my piano teacher who introduced me to the book *Drawing on the Right Side of the Brain,* so I think, off the top of my head, the idea is that the right side is the [*hesitantly*] logical side and the left side is the creative side? Is that what that myth was?

**Alie:** I think so.

**Eugenia:** Right. So, I'd like to stress that I'm pretty sure it has all been debunked and that both sides of the brain work together and are very highly connected.

**Aside:** So, while the hypothesis was flipped and the left side of the brain is supposedly logical, the right is supposedly creative, it's been flimflammed by medicine itself. For more on this you can read, "An Evaluation of the Left-Brain vs. Right-Brain Hypothesis with Resting State Functional Connectivity Magnetic Resonance Imaging," and you've got to use your whole brain for that study because it concluded from over 1,000 scans that there's no evidence that the people nestled into their brain imagining chambers use one side of their pumpkin more than the other. Rather, your whole shebang is interconnected, and "The two hemispheres support each other in its processes and functions," which is tender and kind. So, if you feel like you need to get it together... Don't worry, you have. You are together.

**Eugenia:** There are people who have either never had one side of their brain or lose the use of it and then the other side is able to compensate. And of course, there's tons of stuff about the plasticity of the brain learning to do things. But even if one side of the brain were logical and the other side was creative, that just panders to the idea that math is only logical and not creative and it's really both together. It's just that when you're doing arithmetic in elementary school or wherever you first do it, that might not be extremely creative. But imagine people who came up with arithmetic in the first place... That's creative!

**Alie:** Augh, I have questions. I have so many questions. And I don't even remember how old I was when I realized, "Ohhh! Everything is multiplied by ten because of our fingers!" It didn't occur to me, the Base 10 thing didn't occur to me for so long. But where did math come from and how many generations has it been passed down? And if we didn't learn it from someone older than us who raised us, would we even have any capacity to just come up with, you know, theorems and proofs and calculus and everything out of thin air? Or does it really just keep building on itself?

**Eugenia:** Those are fascinating questions and I think those are really great questions. Humans did come up with those things, but it took them thousands of years. People came up with the idea of numbers thousands of years ago but it was ancient cultures. While the numbers that we use today are mostly based on ten fingers, different cultures base things on different things. There are some cultures that base things on eight because of knuckles, and then there are some people who use the spaces between their fingers as well. And there are some cultures who based it on 20. [*"Twenty fingers and twenty toes."*] And the number system in French has traces of that where 80 is *quatre-vingt*, four twenties, and then 90 isn't 90, it's four twenties plus ten because it's as if you're counting up in twenties. So, there are different things but then this Base 10 thing has really taken over.

**Aside:** So, Base 10 systems have been used for probably as long as we've had ten fingers. Though the written records go back to 3,000 BCE in Egypt, it wasn't until between 100 and 400 years into the Common Era that the Hindu-Arabic numeral system of zero to ten kind of won out. This number system has only been in use in Europe for the last 1,000 years but yeah, it goes far, far beyond that in different forms. But staring at your hands for a while, that's math people.

**Eugenia:** There were some ancient cultures, I think it might have been Mayan cultures that used base 60 which is why there are 60 minutes in an hour and 60 seconds in a minute.

**Alie:** Nooo.

**Eugenia:** Right, so many of our things are in tens, the lovely American system still uses Fahrenheit which doesn't fit well with hundreds.

**Alie:** No, it does not. [*laughs*]

**Eugenia:** But we have this thing with 60 seconds in a minute and 60 minutes in an hour and 60 is a great number to use because it has a lot of factors and so you can divide an hour into a lot of really nice chunks. Whereas if we went decimal on time, I think there's some fantastic society somewhere that thinks we should go metric on time and have 100 minutes in an hour, we would actually not be able to divide it up into quite so many handy units. We wouldn't be able to do a third in a handy way. So, we can divide an hour into half, thirds, quarters, fifths, tenths, twelfths; we can do all sorts of things. So, 60 is a pretty good number for that but the whole ten-finger thing eventually took over.

To answer your question about if we grew up and nobody older than us taught us math, would we be able to come up with all of it? Here's what I think, and this is just pure speculation. I think it would be hard to do that in a single lifetime. It did take humans thousands of years to get to the point we are. And I think it's amazing how fast an individual human is now able to learn all of those things that it took humans thousands of years to learn and it's because we communicate with each other. So, it's really dependent on people who already know it passing it down to the next generation. If we each had to develop it from scratch, it would take a really long time and I don't know how far an individual would get.

**Alie:** Well, do you think there are any math systems that have been completely forgotten that some people cultivated for a couple thousand years, then there just wasn't a record of it, and we just

have no idea that there's a whole math system based on Pi, or the Fibonacci sequence or, like, 7 or something?

**Eugenia:** Almost certainly. Especially because so many cultures pass things down from generation to generation and then maybe died out, or got killed off by white European people, or are living uncontacted somewhere. I think that there are certainly pieces of math that are obsolete now because we've developed more technology. So, for example, there's the whole math of the slide rule. [*"The what? ... What?"*] My parents' generation had to learn how to use a slide rule which is a really clever device for multiplying large numbers together using logarithms. The thing is, we just really don't need that anymore because we've got calculators.

**Aside:** So, that slide rule system was invented by a dude named Edmund Gunter in 1620 and that was the same year that the Mayflower crashed the party that's now known as North America. The slide rule was technically an analog computer, and it had the ability to glide to different positions to reveal these complex math solutions. This is how folks conquered big multiplication and division of numbers until about the 1970s when electronic calculators just beep-booped their way onto office desks next to ashtrays and Diet Pepsi and became accessible and commonplace. Now, as for this so-called slip stick, it became obsolete, partly because you could not write "boobies" upside down with it.

**Eugenia:** So, the slide rule has become obsolete, I don't know how to use one myself. I expect my parents had it drummed into them so hard that they could still do it [*Alie laughs*] if someone presented them with a slide rule. And I'm sure there's somebody out there who still loves using their slide rule.

**Alie:** I mean, I remember the anxiety of how to afford a Texas Instruments TI-87.

**Eugenia:** Oh, graphical calculator.

**Alie:** Yeah, like, needing one of those in high school being like, "I need $109 for a calculator the size of a brick." [*laughs*] Maybe that's not used anymore, maybe it is in testing situations.

I know you get asked this all the time, but who is good at math? How much is it aptitude? How much is it attitude? How much is it access? And why are we so afraid of it? Why do so many people throw their hands up and say, "Mm-mm. Nope, I suck. Byeee. You split the bill, I'm not dealing with it."

**Eugenia:** So, first of all, I think it's mostly access and how much help you had and how much that help was specifically helpful to you. All the scientific research at the moment points to brains being spectacularly plastic. Neuroplasticity, it's extraordinary how much brains can change according to how they are used and how they are stimulated.

**Aside:** So, you *can* coax your brain toward a better life which means that maybe one day I will be good at dancing.

**Eugenia:** So, there is almost no evidence, there's basically no evidence to show that there's some kind of hard wiring at birth that means that some people are destined to be better at math than others. In my previous book, *x + y: A Mathematician's Manifesto for Rethinking Gender,* I talked about this a bit because there are still some people who think that maybe there's some biological reason for men to be better than women at math and therefore there's nothing we can do about it. The scientific evidence to back this up is so thin that it's actually laughable. I mean, I laugh at it, that means it's laughable right? [*Alie chuckles*] Because how can you even tell that something is hard-wired at birth except by testing newborn babies? How do you even test newborn babies? They don't do anything. [ *Alie laughs*] You can't get them to do anything. [*"Just hanging around."*] So, the idea that anything you can get a newborn baby to do is going to be indicative of their future math ability is

just ludicrous to me because math ability is a really complicated combination of things, it's not just about how fast you can do arithmetic.

So, I always say that the things that you can test in lab-controlled situations are necessarily very restrictive, just like you can test how hard people can sprint the 100 meters and I don't think anybody really argues with the fact that the fastest man can run the 100 meters faster than the fastest women, it's to do with body strength and stuff like that. But ultramarathons, women have been beating men at ultramarathons. I can't remember how long counts as an ultramarathon, but it might be 250 miles or something.

**Aside:** Okay, so technically everything over 26.2 is an ultramarathon but the longest and the most grueling is the Hong Kong 298 K with no stopping, or sleep, or support on the trails; just two to three days of continuous running. Why? Why, why? Why? Why?

But take a gander at this one article from 2021 titled, "Why Women are Faster than Men in Long Runs," and you'll learn that the men among us tend to have larger hearts to pump oxygen for powerful sprints and more muscle mass to power those bursts of energy. However, that's the ganders. The geese in this situation, lady athletes, excel at endurance due to a multitude of factors such as a higher body fat percentage that helps when they hit a wall, figuratively, more slow twitch muscle fibers, and yes, emotional resilience, in general. Because some of these bodies have thrust a whole person out of their more sensitive aperture so maybe an ultramarathon is like a walk in the park, just without ever stopping until you've collapsed at the end.

**Eugenia:** And that's a really complicated combination of skills, much more complicated than running the 100 meters, which isn't to say that running the 100 meters isn't hard, it's just a much more focused thing whereas an ultramarathon involves planning, strategy, self-knowledge, pacing. And math is like that because math isn't just about memorizing things or manipulating large numbers. Math is about spotting patterns and being able to perform abstractions in order to see patterns that previously weren't visible and having ideas for how to group objects together to make structures that will be useful to us. It's a bit like designing a useful tool for building a house except that it's an abstract tool for building ideas.

**Aside:** Okay. So, it's like a hammer to drive nails versus the idea of a hammer to drive the idea of a nail which can be applied to the mathematics of the physics of the fabrication of the tools to drive the nails, which becomes the real hammer. Woodworkers, you love math.

**Eugenia:** So, how on earth do you measure a biological predisposition for doing math? They're not skills that are just something that you can be born with. How are we going to test whether a newborn baby can do that? We can't.

**Alie:** What do you think about Common Core? I don't have kids but all I know is that my friends with kids seem horrified or confused by Common Core. I don't quite understand what it is. But why has there been this shift in the way that we're teaching math in the last ten or so years?

**Eugenia:** The reason there's been a shift in the way that we're teaching math is because most people have acknowledged that it wasn't going very well [*Alie laughs*] it's just that people haven't really agreed on what to do about it. I think one of the problems with changing the system is that a lot of... Teachers don't get autonomy over what they're allowed to teach, they get it plonked on them, "Now, you have to teach like this," and that's that, and then you have to prepare people for standardized tests, and then you get judged on how they do on those standardized tests.

I think that anytime that we're aiming to teach people content, like, can you do this thing at the end of it, then that is going to be less successful than teaching them basic appreciation and allowing teachers more autonomy to teach the things that they care about in the way that they care about.

And as the world changes, some basic things become less important just like the slide rule is not important anymore and, controversial idea, but I don't think that long multiplication is important anymore either now that we've got calculators.

**Alie:** Oooh!

**Eugenia:** It's just like learning to ride a horse isn't important anymore, which doesn't mean no one should learn to ride a horse. [*Alie laughs*] If someone loves riding a horse, great! But it's not a crucial skill for most people's daily lives.

I think that sometimes parents get really upset if they don't understand the work that their children are being asked to do. I've talked to many math teachers and the parents complain to them that it's not like it was when they were young. But then the teachers say to them, "Well, did you like math?" And they go, "No, I hated it." And they go, "Well, why do you want me to do that to your children?"

**Alie:** Aww. [*laughs*] That's empathetic, that's nice.

**Eugenia:** And then sometimes people say, "It's terrible, I can't help my children with their homework." And sometimes I want to go, "Well, don't help them with their homework then. It's their homework!"

**Aside:** Okay, this just in. It turns out that I had no idea what Common Core really meant because I don't have kids and I don't listen well. So, Common Core was adopted in US states around 2010 and is actually the set of standardized assessments measuring where kids should be for every school year, but that term, Common Core, often mistakenly is applied to this new way of teaching math that is more intuitive and is actually a very old way of doing math.

So, instead of going and fetching a piece of paper to figure out what's 63-42 and then borrowing some numbers and stacking figures on top of each other, kids learn that well, if you add 1 to 42 then 63 minus 43 would be 20 so it's 20 plus 1 which is 21. Because we all have pocket computers for the bigger arithmetic issues, teaching these quicker and less fussy ways of handling numerical concepts is more valuable, and future generations will probably thank us when it comes to adding tips to dinner bills, that is if American restaurant workers are still making minimum wage and at the mercy of grouchy customers to actually pay for their rent. We thought we'd have flying cars, but we really just want healthcare.

**Alie:** Well, I wonder, how do you think the world will change with a new generation learning math in a different way? Do you think we'll have more mathematicians, more statisticians, more scientists? Or do you think we'll progress even faster through mathematics? Is that a good thing?

**Eugenia:** I'm much more worried about the people who fall off and get put off and get traumatized by it. What I would like to see is not more mathematicians and more scientists, it's fewer people who hate it, that's what I really want to see. Partly because when there are half or more of adult humans who either hate math, are traumatized by it, or are actively hostile toward math and science, we've got problems with persuading people that things like vaccines are real, the pandemic is real and we need to do something about it, that climate change is definitely something that we need to worry about.

I think that that's a big problem for the way that society is going if people are ready to just believe those kinds of lies and I do think that my background and training in abstract mathematics really helps me to not be manipulated by people who are lying to me and it helps me always to be aware of the frameworks for finding out whether information is good or not and deciding whether something that someone is saying is probably true or not. I think that that is all part of what I think education should be aiming for, not can you multiply these large numbers together? Can you

calculate this thing and get the right answer? Can you solve this equation? But can you think clearly about the world around you? Can you make sure that people don't manipulate you and can't lie to you about things just so that they can get your vote or your money? And can we make a contribution to the world that benefits more people and not just ourselves?

**Alie:** The way that social media is, I feel that we're going toward, kind of, a quantitative rather than a qualitative assessment of our lives and maybe there creates a little bit of an anxiety around math there too and we look at how many followers, how many likes something has. We've really started to introduce numbers to things that are much more qualitative.

**Eugenia:** That's a really interesting point, yes. I think it's because society is trying to rank everything all the time and it starts in school because the system tries to rank students but then we get into this frame of mind where everything has to be ranked by a number. It might sound funny because I'm a mathematician and I'm saying we shouldn't rank things by number. [*both laugh*] But I mean, case and point is that the School of the Art Institute, where I teach, we don't have grades, so there is an understanding that we're not trying to rank everybody by a GPA because there are no grades. And I just think that's wonderful so that we can focus on educating rather than ranking.

**Aside:** For more on this you can see the 2021 paper, "Gradeless Learning: The Effect of Eliminating Traditional Grading Practices on Student Engagement and Learning," which notes that:

> *Throughout [their] study, it became clear that students want to learn. Accurate feedback is a vital part of the learning process, but grades are not... The traditional grading systems pits students and teachers against one another, often leading to either side bickering over fractions of percentage points.*

Which I guess is applied mathematics, but I don't think that's the lesson here.

**Alie:** And I wanted to ask a little about some basics for people who maybe are not math majors but when things go from numerical to letters, where in the learning process of math from like, arithmetic to pre-algebra to algebra to precalculus to calculus, where do things start turning from numbers into letters? [*laughs*] And why does that happen?

**Eugenia:** Thank you! That is one of the questions that I address in the book because it is something that people say to me a lot, like, "I was fine with math until numbers turned into letters. Why did we do that?"

**Alie:** Exactly.

**Eugenia:** So, we're thinking about the idea of a person, so we don't name them because we don't know who they are. That's why we do that with numbers as well. I also introduced it like a murder mystery where somebody is a murderer and you're trying to find out who they are, but you can't refer to them by name yet because you don't know who they are. [*Alie laughs*] So, you gather a whole load of evidence about them, and then you pin them down and go, "Aha! It was actually James." [*"How could you?"*]

Often in math, we're trying to find out what something is, but we don't know what it is yet so how can we refer to it? So, we use something like a pronoun but it's a letter because that's what we do in math instead of a pronoun and then we gather evidence about it and so we say, "Oh, well it's related to this other thing like this and when we do this to it, it behaves like that, and when we do this to it..." So, it's like 20 Questions, you say, "What happens when you do this? What happens when you do this to it?" And then you find all these relationships. So, that's what solving equations is about. It's about putting that thing, we don't know what it is yet, into a relationship where you've found out various aspects of its behavior and now you find out, now you can pin down what that

thing actually is and that is the point of using letters and that is the point of solving equations. It really is like a murder mystery. So, anyone who enjoys any kind of murder mystery, I think it's math.

**Aside:** One thing that does not embarrass me is asking really basic questions for me and for the good of all of us, such as: What is the difference between a logarithm and an algorithm? They sound alike, are they friends?

**Eugenia:** A logarithm is very different from an algorithm. A logarithm is a particular function and it... I'm now doing hand motions, that doesn't help on an audio... [*both laugh*] But the graph of a logarithm, it starts down at infinity, and it goes up really fast and then it tails off, so it's kind of like the opposite of an exponential, so much so that it actually *is* the opposite of an exponential; it's the inverse of an exponential function. So, that tails off as it goes along. That's completely different from an algorithm.

An algorithm is a method for doing something and it's a particular form of method, like a really, really step-by-step recipe, a step-by-step process that you could tell a computer to do. So, for example, the dreaded long multiplication is an algorithm, it's a step-by-step process whereby you can follow these steps and multiply large numbers together by following these steps all the way through. But the algorithm says, "If this happens do that, now if this happens do that." It's like a flow chart. So, that's not really math and that's why I say that we don't really need long multiplication anymore, because it's an algorithm, it's a handy algorithm for doing something but it's not really math. When people say, "the algorithm," are you talking about the internet?

**Alie:** Yeah, "The algorithm is showing my videos," or "The algorithm wants me to listen to the new..."

**Eugenia:** So, that's a particular algorithm that the internet or most places we interact with on the internet, use some process for deciding how to show you something next. It's a bit murky exactly what their process is, and many people think that there's something nefarious going on behind it, which there probably is, and it's probably based on money. So, they have applied some step-by-step algorithm and that one really is implanted by computer to say, "Based on this person's previous activity, follow these steps and show them this next thing." That's kind of The Algorithm.

**Aside:** So, this is the math that expertly hooks us with engaging but ultimately never satisfying and infinity-like scroll of content, just harvesting our tastes and churning out more like it back with this boggling speed. Now, Twitter looks at half a billion tweets every day and then decides exactly what to show *you*. One article called, "The TikTok Algorithm Knew My Sexuality Better Than I Did," pretty much says it all. We cover more of this in, yes, the TikTokology episode with your favorite scicomm-er on there, Mr. Hank Green. And yeah, we will link that in the show notes.

**Eugenia:** There are many other algorithms. Sometimes algorithms are great because they help us conserve our brain energy and I think that's really important because our brains are finite and very puny [*Alie laughs softly*] and so if we can conserve that energy as much as possible, that's really helpful. So, I personally, have all sorts of algorithms for helping me run my life and this may be me as a mathematician speaking but it's because I don't want to use up my brain energy on something that's kind of irrelevant.

**Alie:** What do you have? Tell me! Tell me! Tell!

**Eugenia:** For example, I have algorithms for when I buy more coffee, for example. [*Alie laughs*] [*"Hey? Tell me everything."*] I buy five-pound bags of beans but then I keep a pot of them on the counter so I refill the pot on the counter from the bag of beans and then once the last bit of the bag of beans has filled the pot then I immediately buy another bag of beans so that it's ready by the time I get to the

end of the pot, and I don't have to think about that. Maybe one day I can have a smart coffee bean pot that will automatically order it for me, but that's my algorithm for coffee beans.

**Alie:** I love that those are algorithms. Can you tell me some other places where we don't realize there's math just everywhere? I know a video going viral, I know you've seen sine waves in your wraps and burritos and there's math in braids and challah. [*"Holla!"*] Where are some of the unexpected places where math is really making our lives amazing?

**Eugenia:** Well, one thing that I do when I'm walking across Chicago which is on a grid, is that thing where I walk in one direction until I hit a stop sign. If I don't get the light on a crosswalk, then I turn and take the crosswalk going the other way and then I keep going in that direction. So, that's my algorithm for walking across Chicago. And there's some math in there that's telling us that wherever we turn, it doesn't matter. If I need to go five blocks east and ten blocks north, then it doesn't matter where I turn, it will still be the same distance of walking as long as I consider that turning doesn't exhaust me and that's actually a part of metric spaces. A metric is a more general form of distance, and we think about distance, usually distance as the crow flies, but you don't fly like a crow when you're walking across Chicago because there are buildings in the way. [*Alie laughs*] So, the distance we *actually* need to go to get somewhere is not the distance as the crow flies, it's the distance along this grid and so we need to know that it doesn't matter where we turn and that's intuitively kind of clear, right?

And then you can do things like, say, what's a circle if we're using this form of distance? Because a circle doesn't quite look like a circle anymore, it looks more like a diamond shape but that counts as a circle because it's all the points that are four blocks away from you and I think that's kind of hilarious because I like things that challenge the received wisdom which makes me sound like a pointless rebel. But I like to become a pointful rebel because math is about not making assumptions that you don't need to make.

I think that that's really important in life as well because a lot of the problems with society come from people making assumptions about other people that you don't need to make, which doesn't mean we shouldn't make any assumptions about people because actually, that's impossible. As soon as we meet someone, we have to start someone, so we have to have an instinctive, intuitive gut response to them, but the really important thing is to be ready to change it when we get new information. Math is really about that. You can be aware you made them so that if they turn out not to be right, you can change them and then get a different result.

**Alie:** It seems like once you embrace math you can understand that it can be very empowering, and it can offer a lot of clarity.

**Eugenia:** That is certainly what I think, so if that's the impression I've given you, that's fantastic! And I've just realized, I don't think I really addressed the part of your question earlier where you said, why are people so put off it and afraid of it? And this is what makes me sad because I think it's there to help us, and I think it's not presented like that enough.

**Alie:** Okay, I have some questions from listeners, they know that you specifically are coming on.

**Aside:** But first, let's raise the bottom line of a cause of the ologist's choosing. Eugenia pointed us toward MathCirclesOfChicago.org whose mission statement says:

> *We offer engaging, flexible, and free math programs to students in grades 3–12. We focus on reaching Black and Latino communities and other communities where most children live in low-income households.*

You can find out more at MathCirclesOfChicago.org and that will be linked in the show notes and that donation was made possible by sponsors of *Ologies*.

[Ad Break]

All right, let's divide and conquer your queries.

**Alie:** One wonderful one that was asked by Mallory Skinner, Doug Paice, Maddie S, Talia Dunyak, Emily Staw-fur, Devon Naples, [*laughs*] Devon asked...

**Eugenia:** Did they all ask separately?

**Alie:** All asked this similar question.

**Eugenia:** Oh wow!

**Alie:** They want to know: Please explain infinity in a way that my brain can reeaallllyy comprehend. [*laughs*]

**Eugenia:** Oh! Well, you know infinity is really difficult. If you feel like your brain isn't comprehending it, then maybe it is.

**Alie:** Oh! Wow! [*"Go on."*]

**Eugenia:** It's *supposed* to be mind-blowing. People who think they understand infinity are kind of just deluded. So, I think the correct feeling is to feel like it's too mind-boggling to get your head around, that's the whole point of it. It's bigger than anything we can think of, and it behaves in really weird ways. And I think what often makes some people mathematicians and some people math-phobic is embracing the feeling of not understanding something rather than taking it as a sign that you're bad, taking it as a sign that there's something really interesting going on.

If you go to the edge of a cliff, I don't like looking over the edge of a cliff because I'm worried I will fall and die [*"Same."*] and I think that there's a similar kind of vertigo that sometimes people get when thinking about math concepts and people have been so humiliated and traumatized by their past math experience that it feels like they're going to get hurt if they look over that cliff. What I want to say is that you're not going to die anyway by looking over the mathematical cliff, you might get some emotions dug up from some past negative experiences, but the good thing is that you won't physically die by looking over the math cliff. The thing that's over the math cliff is something that maybe kind of gives you intellectual vertigo. I don't run away from those things, and I think that's the only difference. It's not that I'm better at it or something, it's just that I have decided that I'm interested in it and that it's not a sign that I'm bad at it if I don't understand it.

I don't understand anything if I think about it hard enough. The number 1, what even is that? I can't understand the number 1. If I don't understand the number 1, how am I going to understand infinity? But that's what drives us to do more research, it's the feeling that there is always more there to understand than we *want* to understand. We don't go, "Oh, I don't understand this." We go, "Oh, I want to understand more, I'm never going to understand all of it but that doesn't mean I'm going to give up, I'm just going to keep trying to understand more all the time I can."

**Aside:** Some people call this a growth versus a fixed mindset and fixed mindsets tend to be afraid to try and fail but growth is like, "You know whatever happens I learned something." From personal experience, two of the smartest people I've ever encountered, my friends, Doctors Casey Handmer and Christine Corbett, have worked at NASA, Casey now heads Terraform Industries, working on these new ways to capture atmospheric carbon and turn it into natural gas. One thing about the two of them, and they're married, is that they just try stuff. They want to learn something, they just dive right in. As a result, Dr. Corbett has an extra master's in creative writing

and just got a black belt in kung fu. They are smart people who ask smart people sometimes basic questions and Casey once told me the key to how much they get done is they just learn shamelessly from any failure. They get it, they keep moving. So, they are heroes, they are not zeroes. Oh, which reminds me that Brenna had a question.

**Alie:** On that note, Jenny Lowe Rhodes, Maggie Morgan, Starr, Lillian Wright, Christine Pikstein, Meg C, Libby Hagedon, and Brenna Pixley all have questions about zero. Jenny wants to know: How long has zero been a thing? Maggie is like: Is zero a number?

**Eugenia:** Great questions! I do know that it has troubled people for thousands of years about whether it really ought to count as a number or not. My recollection is that maybe the Greeks or the Romans, one or the other, or maybe both, were really unconvinced that zero should count as a number, philosophically it really bothered them, and that really held them back.

Here's the thing, you can decide whether you want zero to count as a number or not. The question is, how does it help us? There are often no right and wrong answers to these things. Mathematicians say, "Here's a world in which this thing is true, and here's a different world in which something else is true. Which one is going to help us?" So, we can make a world in which zero isn't a number, we're not going to be able to do very much there. Zero is a really helpful number to have around because if we're going to represent nothing, what are we going to represent it with? If we subtract five from five, what do we get? If we don't have a number called zero, we can't do that and then we can't really make negative numbers either and if we can't make negative numbers, there are all sorts of things we can't do.

So, if we *do* call zero a number, then we do get to do all these things so that's why mathematicians generally have decided that zero should get to count as a number, just so that we can do all of those things, it's just language. So, as long as we can manipulate zero in some way, we can get to do those things. If you feel like you don't want to call it a number then that's fine, don't call it a number! As long as you can still manipulate it in those ways because it's really helpful to do it.

**Aside:** So, zero. We can wrap our brains around that. Some of you had a weirder concept plaguing you such as Anna Thompson, Jennifer Lemon, Ariel Vanzandt, Kristina Kunze, Eleonoora, Renaud Banville, GJ Wyatt, Tony Vessels, Sarah, Val McKelvey, Phylicia Chandler, Valerie Bertha, and first-time question-asker Bill LaBranche and...

**Alie:** Kristina Kunze asked: Imaginary numbers, what the fuck? [*both laugh*] What is an imaginary number? What's going on?

**Eugenia:** Yeah, this is great! And this is a great thing to say after is zero a number because some people go, "Are imaginary numbers a number?" So, mathematicians really don't like having rules imposed on them and it makes me sad but one of the things that puts people off math is that there seem to be all of these rules that you have to follow. Whereas mathematicians go, "Wait, okay. We had to follow those rules in this world, but I don't want to follow them anymore. Can I build a different world in which I don't have to follow those rules?"

So, one of the rules mathematicians don't like having to follow, and I do talk about this in the book, is you can't take the square root of a negative number. Why can't you take the square root of a negative number? Because if you try squaring numbers, square rooting is the opposite of squaring. So, you're saying, "Is there any number such that when I multiply it by itself, I get -1?" Well, let's think about that. If I multiply a positive number by itself, I get a positive number. If I multiply a negative number by itself, I also get a positive number. [*"You are employing a double negative."*] So, we seem to be out of options for things we could multiply by themselves and get a negative

number. But mathematicians go, "Never mind, I'll just make something up and see what happens." [*Alie laughs*]

So, it's called an imaginary number because we sort of just imagined it, and the wonderful thing about abstract concepts is that as soon as you imagine them, they become something that exists because it's an abstract concept. So, I would love to imagine my dinner and for it just to exist. It doesn't work like that, or imagine some dollars in my bank account, oh there they are! But I love that about math, you can just imagine something into existence. So, you just imagine that there is something and you take its square and it is -1.

So, what is it? Well, it doesn't really matter because, in math, it doesn't matter what something is, it only matters what it does. And I think this is a wonderful thing to think about in life as well because really, it shouldn't matter what somebody is, it shouldn't matter what the color of their skin is, or what they look like, or how large they are, or what gender they are or anything, it should only really matter what they do. Are they a nice person? Are they helpful? Are they kind? Are they generous? Those kinds of things. So, in math, we put aside the question of what that imaginary number is, we just say, "What does it do?" And it's like when children make up a game, they will make up a whole world and they will play that game and that's what math is [*Alie laughs*] but then it goes one step further because it goes, "Oh, is this helpful? Crickey, it actually is." [*Alie laughs*] So, it starts off as being just some kind of ludicrous game that we're playing in our heads, but it turns out to be really helpful for solving problems in physics, isn't that extraordinary?

And I just think it's extraordinary that this thing that we made up, that doesn't have any physical reality to it, is helpful in physics because what happens is that you draw pictures of it and when you have ordinary numbers, you draw them on a number line. We put numbers on a line and it's one line. A line is very flat, it's one-dimensional. But if you add imaginary numbers into that mix, where do your imaginary numbers go? Well, they're not on the line so they just have to go in a different direction, so you can just make them go up the page and then when you mix all those things up, you get a two-dimensional space instead of a one-dimensional space and in two-dimensional space, you can see beautiful patterns that you can't see in one-dimensional space because it's so incredibly thin, a line is just too thin, you can't see patterns, whereas in the two-dimensional space, you can see gorgeous patterns.

That's how it's helpful in things like physics because you work out the patterns using the two-dimensional space and then once you apply it to the real world again, you just take the part that's on the line, but it's just that you can recognize what the patterns are because you were exploring them in two-dimensional space. It's kind of like if you're clearing out your closet you need to take everything off the rail and spread it out on your bed before you put it back on the rail again.

**Aside:** So, behind every perfectly Marie Kondo-ed closet is the chaos and the pain and the discovery and the beauty of purging and whittling what's hiding in the universe's little crevices and corners.

**Alie:** Kind of on that note too, Phylicia Chandler and James Dean Cotton want to know about the Fibonacci sequence. Phylicia asks: Why do we see it so much in nature? I imagine that Dan Brown's *The Da Vinci Code* really put the Fibonacci sequence on the map. [*"I'm into something here that I cannot understand."*] What does math have to say about that particular equation in nature?

**Eugenia:** Perhaps I should remind everyone that the Fibonacci sequence starts 1,1 and then you add up the two previous numbers to produce the next number. So, you get 1 add 1 which is 2, and then you add that to the previous number, 1 and 2 which is 3, and then you get 5, and then you get 8, and then you get 13. and so on.

**Aside:** Okay, so just a quick primer, Fibonacci Leonardo Pisano was an Italian guy who, around the year 1200, wrote a book about math and popularized the standard Hindu-Arabic numerals in Europe. Everyone loved him for it, thought he was dope at math, and then he died, and everyone forgot about him for like 400 years until the 1800s. Two things, he didn't actually invent or discover the Fibonacci sequence, that dates back to at least 300 BCE when this Indian poet, Pingala, was already down with it. Not Fibonacci's fault that we named this sequence after him.

Another thing is that Fibonacci was from Pisa which is where the Leaning Tower of Pisa is and it was built around 1200, during his lifespan! So, where was he when it came to applied mathematics? [*"Yeah, I'm... super busy these days."*] Also, I didn't intend this, but worldwide Fibonacci Day is this week, occurring on the same day as the dog holiday Wolfenoot, and American Thanksgiving. But every year, you can celebrate Fibonacci by eating artichokes and Romanesco and pineapple because 1123 is Fibonacci-esque, even though again, it wasn't him who discovered the sequence. Also, I need you to know that I only found out about Fibonacci Day because I googled, "Was Fibonacci hot?" and I happened upon a blog that mentioned 1123 and that there is little known of his physical appearance. I don't know, I just have a hunch, I bet he was hot. Maybe like a 10.

**Eugenia:** I think the first thing to say is that it is not quite as prevalent as its popularity may suggest. [*laughs*]

**Alie:** Okay! [*laughs*] Good to know.

**Eugenia:** It's like the Golden ratio, which isn't nearly as prevalent as its popularity would indicate either. But I think the reason is that nature... I don't want to anthropomorphize nature too much, but nature is trying to do as much as it can with the smallest starting point as possible because that's kind of efficient and why that is the case is a whole deep philosophical or possibly biological question but it may be to do with survival of the fittest and evolution, the things that survived are the ones that did the most possible stuff with the smallest possible amount of information. So, sometimes it really is a sheer mathematical situation.

So, for example, the spirals on a pineapple are typically Fibonacci numbers. So, if you count how many spirals there are in each of the different directions, there are three different directions that spirals on a pineapple can take; there's the really vertical direction, there's the more obvious slanty direction and then there's the really, really, really slanted direction that's less obvious. The thing is that geometrically, the two smaller numbers have to add up to the bigger one, you can work that out on any shape at all. Why they typically turn out to be Fibonacci numbers may be something to do with the way that the little fruitlets grow and it's the same with the leaves on the stem of a plant. They grow at different angles spiraling around the plant, possibly to get as much sunlight as possible. The angles, the way that the angles work in a Fibonacci sequence is to try and make sure the next time a leaf lines up with the one beneath it, it's as far away as possible.

It's often only a very small part of the Fibonacci sequence so it's just two consecutive numbers of something. So, that's why I think it's not quite so prevalent. If you have leaves spiraling around and it happens to be in a pattern of 3 and 5, that's only two numbers out of the Fibonacci sequence so I wouldn't go, "Wow, it's a Fibonacci sequence!" [*Alie laughs*] Maybe it's just 3 and 5 and it's nothing to do with the Fibonacci sequence at all. Sometimes the reason that something that's constructed very simply in math pops up all over the place is a beautiful and maybe slightly mysterious thing and that's one of the things that is wonderful about it and that is maybe not an answerable question. This is why sometimes people believe in a higher being because it seems like some higher being created that. But I personally don't feel the need to say it was a higher being, a specific delineated higher being. I just think that math is a higher being. [*AI voice says, "Math is my copilot."*]

**Aside:** This one was on the minds of Jean Pompeo, Milan Ilnuckyj, Mushroom Morgan, Rachael Gardner, Taylor, The Ren You Know, Corinna Regan, Felix Lasselle, Claire Nurc, and listener Victoria Sauter who wrote via Patreon.com/Ologies: I am so excited you are talking to Eugenia Cheng, I have a huge math crush on her, I have two of her books. As a teacher, I believe math is for everybody and I try to make clear that math isn't an isolated subject when we use it to understand all parts of the world. Suggestions to bring math into the living room, so to speak, that is a little juicier?

**Alie:** Last question from listeners... So many people wanted your expert advice. Elta Sparks wanted to know: Any recommendations for teaching number sense to very young students? Blessed Are The Cheesemakers asked: Math professor here. Do you have any advice for college professors (or any teachers generally) who want to improve their teaching? So, any advice to people teaching or learning math that you feel has been empowering to people?

**Aside:** See her book.

**Eugenia:** This is why I write all my books, to try and give people ideas and help people get over their past traumas. I think that one of the messages that I most want to say to everyone who is learning math and therefore, I want everyone who is teaching it to also pass that on, is that if you find it hard, that doesn't mean you're bad at it. You're probably just right, it is hard and that's not a reason to be put off it. If you look around you and it seems that other people are finding it easier, they might just be talking out of their armpit [*Alie laughs*] [*"So to speak."*] in order to intimidate other people because most mathematicians, in fact, every mathematician I know thinks they're stupid and find everything very difficult.

**Alie:** Is that true?

**Eugenia:** Yes. That is the...

**Alie:** [*softly and incredulously*] Really?

**Eugenia:** I think that is a correct impulse to think it's hard because it is hard. But the point is, we can keep understanding more of it all the time and I think that celebrating the questions that children ask and not being afraid if it's a question that you don't know how to answer because then you can celebrate *them* for having asked a question you don't know how to answer and then we can all learn about how you discover answers to questions. If it's a question that nobody knows the answer to like, why does the Fibonacci sequence come up in nature, then you can say to a child, "If you become an expert in that field, *you* could be the one who answers it and then *you* could be the one going on this podcast explaining it to other people." [*"Please do."*]

**Alie:** What about, I always have to end with these, what's your least favorite thing about what you do as a professional abstract mathematician?

**Eugenia:** I think it is overcoming peoples' misconceptions and it's the fact that those misconceptions are so deeply embedded culturally, and that's what I'm trying to overcome. I'm not trying to get everybody to love math because we don't all have to love the same things. I'm just trying to show it for what it really is. If everyone saw it for what I think it is and they still didn't like it then, you know, fine, we can all like different things. It's the fact that some people see some really, really narrow, shallow side of it and then write it off from their lives when I think it can help everybody. I find that frustrating but that's the challenge, to overcome those deeply embedded misconceptions. It's been so great talking to you about it because it doesn't sound like you have those things. But sometimes, even getting something published can be difficult because the people who want to publish something have their own misconceptions and go, "Well, I want you to write about math, but this isn't math." So, then I have to persuade them that this is math.

**Alie:** What about your favorite thing? Or your favorite number? Your favorite theorem? Your favorite moment? What has just made your heart sing the most in your career?

**Eugenia:** My favorite thing is being able to help people understand something they didn't previously understand and seeing their gasps of delight when some mathematical thing has got them to be as excited as when I see it. That is what gives me the most joy in math I think, being able to give that joy to other people.

**Alie:** I wonder if there's a word in any language for the moment when something clicks, when you are figuring it out, figuring it out, figuring it out, you don't get it, you don't get it. And I've sat in calculus classes before, I *don't* get it. And then suddenly, something changes over and you're like, "I get it, I get it, I get it," whether it is a joke or a theorem or something. I wonder what is happening in the brain because that moment is just unlike anything else when you finally get it.

**Eugenia:** And it really feels like pieces falling physically into place, doesn't it?

**Alie:** Mm-hm. It does, yeah.

**Eugenia:** I'm fascinated by the brain; I'd love to try and do brain scans while I'm doing things like that to try and see what's going on.

**Alie:** This has just been such a joy.

**Eugenia:** Aww, I've really enjoyed it too, thank you so much.

---

So, there you have it, ask the simplest questions and you'll learn the deepest truths. For more on that, you can see Dr. Eugenia Cheng's frickin' book which is titled, *Is Math Real?: How Simple Questions Lead Us to Mathematics' Deepest Truths*, which is linked alongside her website and her social media.

We are @Ologies on Instagram, and I guess Twitter but I'm @AlieWard on both. *Ologies* merch is available at OlogiesMerch.com, in case you need holiday gifts. *Smologies* are available for free, they're G-rated, they're at AlieWard.com/Smologies. Those are kid-friendly versions of classic episodes. To join Patreon and submit your questions before recording, head to Patreon.com/Ologies.

Erin Talbert admins the *Ologies* Podcast Facebook group, Emily White of The Wordary makes our professional transcripts, Noel Dilworth is scheduling producer, Susan Hale is our major managing director who also assisted for research for this episode. Kelly R. Dwyer makes the website, Zeke Rodrigues Thomas and Jarrett Sleeper of Mindjam Media worked on *Smologies* alongside our lead editor of this episode and of *Ologies*, the infinitely talented, Mercedes Maitland of Maitland Audio. Nick Thorburn wrote the theme music.

And if you stick around until after the show, I tell you a secret. [*deep inhale*] Okay so, this week it's that I used to make cocktail recipes for cooking sites, and I used to write about nightlife way back when so I'm pretty versed in making cocktails. At a party, people would be like, "We got some peppermint schnapps, a cantaloupe, and Pixy Stix, and some Tabasco, make something out of it, and I can usually whip something up. But I'm not much of a make-cocktails-at-home kind of person these days, pretty chill. But I just found myself making a beverage and I used some lemon powder and some peach Emergen-C, and a heaping scoop of Metamucil and I had it in a Nalgene and I was just shaking that thing up because you have to and I realized that the muscle memory of the cocktail shaking is still there, it's still strong but just of very different contents and very different vibe. But hey, you've got to hydrate, you gotta get those electrolytes, colon motility is important, and so is

math... Math is real... But nothing is real, and life is very beautiful, and Metamucil can be tasty. All right, mmm berbye.

*Transcribed by Aveline Malek at TheWordary.com*

**Links to things we discussed:**

Very long marathons are very long

Anthropometric Comparison of World-Class Sprinters and Normal Populations

The math TikTok that started it all

Eugenia's response to that viral TikTok

Barbie Liberation Organization press video, 1993

Mathematical Treasure: Teen Talk Barbie

Mattel Says It Erred; Teen Talk Barbie Turns Silent on Math

"OPERATION NEWSPEAK" The Barbie / G.I. Joe Voice Swap of Xmas 1993

Barbie Fucks It Up Again: 2014 Computer Engineering Book

How Imgur saved Feminist Hacker Barbie behind the scenes

Feminist Hacker Barbie meme generator

Kathleen Tuite: The woman behind the Feminist Hacker Barbie meme generator

Monad Barbie Comic

The Map of Mathematics

An Evaluation of the Left-Brain vs. Right-Brain Hypothesis with Resting State Functional Connectivity Magnetic Resonance Imaging

History of Base 10

History of Bases Used in Ancient Civilizations

Yes, Men Run Faster Than Women, but Over Shorter Distances and Not by Much

Monad (category theory)

Emotions and motivation in mathematics education: Where we are today and where we need to go

When Do Girls Prefer Football to Fashion? An analysis of female underachievement in relation to "realistic" mathematic contexts

Terraform Industries

The TikTok Algorithm Knew My Sexuality Better Than I Did

Gradeless Learning: The Effect of Eliminating Traditional Grading Practices on Student Engagement and Learning

**Other episodes you may enjoy:**

Quantum Ontology (WHAT IS REAL?)

Dolorology (PAIN)

Fearology (FEAR)

Egyptology (ANCIENT EGYPT)

Classical Archeology (ANCIENT ROME)

Economic Sociology (MONEY/FREAKONOMICS)

Tiktokology (THE TIKTOK APP)

**Ologies info:**

Sponsors of Ologies

Transcripts and bleeped episodes

Smologies (short, classroom-safe) episodes

Become a patron of Ologies for as little as a buck a month

OlogiesMerch.com has hats, shirts, hoodies, totes!

Follow @Ologies on Twitter and Instagram

Follow @AlieWard on Twitter and Instagram

Editing by Mercedes Maitland of Maitland Audio Productions

Transcripts by Emily White of The Wordary

Website by Kelly R. Dwyer

Theme song by Nick Thorburn