WOMAN: OK, what I like about math? I don't know. I like numbers. And if you like money, you got to love math. That's just a natural thing. I love money, so.

MAN: Math is just something that I've been fascinated with since second grade, and it's always just felt really good.

WOMAN: It works in a graph, and you can apply it to nature, and you can apply it to physics. You can apply it to chemistry.

JOE: I find myself thinking in graphs, almost. Like, when you throw a ball, you can imagine the height of it in a graph, or when you're driving in the car, you can imagine your speed in a graph. Everything you do can be represented in a number.

MAN: Numbers don't lie, so I trust them easily.

WOMAN: And I think it's less about knowing the exact equations and numbers than it is just like, knowing how to think mathematically, and thinking like, a logical, problem-solving kind of way. So then, you can apply that to other aspects of your life.

MOLLY BLOOM: Those were competitors at a recent math tournament at Roosevelt High School in Minneapolis. We'll hear more from them in a little bit. But first, let's count it down.

[THEME SONG PLAYING]

CHILDREN: (SINGING) 5, 4, 3, 2, 1. It's time to get our brains on. We're going to get our smarts on. Fire up your neurons. It's time, it's time, it's time, it's time, it's time! Brains on!

MOLLY BLOOM: Hi, you're listening to *Brains On.* I'm Molly Bloom, and I have two co-hosts here with me today, Eisha and Joe. They're 11 years old, and they're on their school's math team. And if you haven't guessed, today is all about the numbers. So do you guys have a favorite number? Eisha, what's yours?

EISHA: Mine is probably 2 or 20, because I was born the year 2002, and I graduate in the year 2020.

MOLLY BLOOM: Do you like anything about the way those numbers act in math?

EISHA: Probably because they're like, even and they divide by a lot of stuff.

MOLLY BLOOM: And how about you, Joe? What is your favorite number?

JOE: My favorite number is 5.

MOLLY BLOOM: Why?

JOE: Well, when you're doing math, they're really fun to work with, because when you get a number with 5, it's an easy division.

MOLLY BLOOM: Excellent. Well, why don't we hear how the high school kids at the math tournament answered the same question.

MAN: I think, honestly, my favorite number is 0. It's just the concept of it. We just think of it as nothing, but we define it as something.

GIRL: I like the number phi. It's equal to 2pi. Everyone knows about pi, but phi is actually easier to use when you're talking about the unit circle, because the unit circle is equal to 2pi, but phi is just once around the circle.

WOMAN: I really like 8, because it's just a fun number. A lot of things go into it, and it can be very helpful in dividing.

MAN: Square root of negative 1. Quick way to go from real to non-real. e to the power of pi times i, the imaginary number, equals 1, which always weirded me out, because it's these three different numbers that don't seem like they should all combine together to form one, and yet, they do. It's confusing, and I'm not really-- I don't really understand it, but I really like the way it works.

MOLLY BLOOM: So, Joe, what do you like about doing math?

EISHA: Well, I like how math is basically a puzzle, and puzzles are fun to solve.

MOLLY BLOOM: So do you know any math jokes?

EISHA: I don't really know any math jokes, but if you write 3.14, and then, if you make it backwards, it's pie.

MOLLY BLOOM: Wait, explain that to me. Tell me more about that.

EISHA: So if you write like, 3, just like, straight lines, and then, a 1 like an I, and a 4.

MOLLY BLOOM: Where it's connected at the top like a triangle?

EISHA: Yeah. And then, if you put it backwards, it's pie.

MOLLY BLOOM: It spells the word pie?

JOE: Yeah. P-I-E.

MOLLY BLOOM: Whoa. I never thought of that before. That's cool. Do any math jokes, Joe?

JOE: No, not really.

MOLLY BLOOM: I only know one joke. Why was 6 afraid of 7?

JOE: Yeah. Because 7 ate 9.

MOLLY BLOOM: Do you ever feel like there's magic hidden in the numbers that you're working with?

JOE: Sometimes.

EISHA: Maybe.

MOLLY BLOOM: Maybe? Maybe it's not clear. So we're going to talk with someone who is going to show us exactly how magical they are.

ARTHUR BENJAMIN: Hi, my name is Arthur Benjamin. I'm a professor of mathematics at Harvey Mudd College in Claremont, California. I am a mathematician and a magician, so sometimes, people call that a mathemagician.

Well, I think mathematics and magic have a lot in common. For example, it's really all about trying to solve for the unknown, right? You see a magic trick, and you wonder, how does it work? What's going on underneath?

And when you solve a math problem, whether you're trying to solve for x, or you see a beautiful number pattern out there and you want to understand, why is this happening? What's going on? I think mathematics and magic have a lot in common that way.

MOLLY BLOOM: And when did you first get interested in magic?

ARTHUR BENJAMIN: Oh, gosh. When I was a kid, I just liked to show off, and I would do anything that would get attention. And gradually, over the years, I would discover or others would discover that I wasn't so good at singing or dancing, but I was pretty good at doing magic tricks. And that stuck.

MOLLY BLOOM: And so, when did you realize there were these little tricks sort of hidden in the math you were taught?

ARTHUR BENJAMIN: I liked to do problems in my head, and I discovered some shortcuts that would allow you to do the problems faster. Can I give you an example?

MOLLY BLOOM: That'd be great.

ARTHUR BENJAMIN: So I'm going to ask you to give me some numbers, two-digit, three-digit numbers. I will try and square them as quickly as you can do on the calculator. So start with a two-digit number and square it.

MOLLY BLOOM: OK. See, 42.

ARTHUR BENJAMIN: Is 1,764. So if you do 42 times itself, you'll get 1,764.

MOLLY BLOOM: Yeah, that was way faster.

ARTHUR BENJAMIN: Let's try a three-digit number.

MOLLY BLOOM: OK, 215.

ARTHUR BENJAMIN: Is 46,225.

MOLLY BLOOM: So how do you-- how do you do that? Is it just years of practice?

ARTHUR BENJAMIN: There's a large practice component, for sure, as well as other shortcuts that you can come up with. If the number ends in 5, squaring a number that ends in 5 is even easier. So give me a two-digit number that ends in 5. In fact, before you tell me, I will tell you how to calculate the answer.

When you square a two-digit number that ends in 5, the answer will always, always end in 25. And to get the beginning of the answer, you take the first digit, multiply it by the next higher digit, and that's how the answer begins. Now, that sounds confusing at first, but let's do a couple examples, and it'll all be clear. Give me a two-digit number.

MOLLY BLOOM: 65.

ARTHUR BENJAMIN: 65. Now, I told you the answer always ends with 25. And how does it begin? It begins by taking 6, because that was your first digit, 6, multiplying it by the next higher digit, which is 7. 6 times 7 is 42. So there's your answer. 42, 25. 4,225.

MOLLY BLOOM: That is so cool.

ARTHUR BENJAMIN: It is cool. Let's do one more exam. Because everyone needs to see two examples to get it solidified. Give me a second two-digit number that ends in 5.

MOLLY BLOOM: 35.

ARTHUR BENJAMIN: 35. Now, you do this with me.

MOLLY BLOOM: OK.

ARTHUR BENJAMIN: So the answer begins by taking 3 times?

MOLLY BLOOM: 4.

ARTHUR BENJAMIN: 4. Which is?

MOLLY BLOOM: 12.

ARTHUR BENJAMIN: So the answer to 35 squared is?

MOLLY BLOOM: 1,225.

ARTHUR BENJAMIN: You got it.

MOLLY BLOOM: Oh, my gosh. You made me feel so smart.

ARTHUR BENJAMIN: Thank you. Well, the goal, my goal in life is not for people to see how smart I am, but to see how smart they can be. We all have an inner mathematician inside of us. It's just a matter of having that unlocked.

Another number that I liked very much as a kid was the number 11, because there was a really fun way of multiplying numbers by 11. Now, if you're multiplying 11 by a one-digit number, it's very easy, right? 3 times 11 is 33, 7 times 11 is 77.

But multiplying two-digit numbers times 11 is almost as easy. For example, let's say you want to do, oh, 32 times 11, all right? Now, let's add the digits. What's 3 plus 2? It's?

MOLLY BLOOM: 5.

ARTHUR BENJAMIN: 5. And the answer to 32 times 11, you just stick that five in between 3 and 2, and you've got your answer. 352.

MOLLY BLOOM: Whoa.

ARTHUR BENJAMIN: So 32 times 11 is 352. Here, let's say the problem was 45 times 11. 4 plus 5 is?

MOLLY BLOOM: 9.

ARTHUR BENJAMIN: 9. And so the answer is 495.

MOLLY BLOOM: Wow.

ARTHUR BENJAMIN: Wow, exactly.

MOLLY BLOOM: That's so cool.

ARTHUR BENJAMIN: Now, before we finish, because I've only shown you half of what you need to know, because if the numbers add up to something bigger than 9, let's say, we had a problem like 85 times 11. Now, 8 plus 5 is 13, but the answer is not 8,135. But we only have room for the 3, but that 1 from the 13 makes the 8 carry, and the answer is 935.

MOLLY BLOOM: That's so cool.

ARTHUR BENJAMIN: I'll do one more example. So 66 times 11. 6 plus 6 is 12, so the answer to 66 times 11 is 726.

MOLLY BLOOM: That is so cool.

ARTHUR BENJAMIN: Play with it, practice with it, and you'll be amazing your friends in no time. I like to say that mathematics is not just solving for x. It's also figuring out why.

EISHA: That was Arthur Benjamin, mathemagician and author of several books, including*The Secrets of Mental Math.*

MOLLY BLOOM: So is there anything in that interview that surprised you or you found particularly interesting?

EISHA: I never knew that like, you can do magic tricks with math, and I also couldn't believe how fast he could solve it. Because that was faster than a calculator. It was like, right when you said it, he solved it.

MOLLY BLOOM: Yeah. It's pretty amazing. It really surprised me. It blew my mind.

EISHA: I didn't know any of those tricks.

MOLLY BLOOM: Now, maybe you can use some of them in your tournaments or something.

EISHA: Yeah. It would go faster.

MOLLY BLOOM: So humans have been doing math for a long time, thousands of years, but it wasn't always the same as it is now. In fact, for a large part of our early civilized history, we were missing a very important concept in math. Can you guys guess what it was?

JOE: 0.

MOLLY BLOOM: That is exactly right.

JOE: Well, I didn't know if that was the right answer, but I knew that in Roman numerals, they never wrote 0, so I thought, well, wouldn't it be 0?

MOLLY BLOOM: In 3,000 BC, an ancient culture known as the Sumerians were the first to use symbols to count stuff, like cows and horses. Basically, they used math to add things up. But they didn't have a symbol to represent 0 cows or 0 horses, and without 0, we didn't have a number we could use as a placeholder or a way to write the answer to 5 minus 5. And without 0 all kinds of much more complicated math that would be hard to describe on the radio would be impossible. So here is a little tribute to the humble 0 in poetry form.

MAN: This poem is called 0, Our Hero. Oh, noble 0, how your legend persists. To think there was a time when you didn't exist. Eons ago, we could count high, we could count low, but we had no idea that equaled 0.

We could count to the heavens, we could count to the stars, but we couldn't count nothings. Twas so bizarre. But in old Babylonia, around 300 BC, a symbol appeared. What could it be? It was two slanted wedges used to hold the place when counting large numbers, kind of like a blank space.

That's not 0, you say. That's just nothing, at best. You're quite right, I reply, but it's a start, nonetheless. Then, in India, sweet India, 650 AD, they used a new number with dots underneath. It meant empty and place, a real 0 ideation.

It soon became part of mathematical equations. From there, it did spread to Persia, at last, where great thinkers used it for algorithmic-type math. 0 then became an oval, that lovely round shape that looks like a man's mouth left open, agape. It took centuries for 0, then, to spread to the West, but by 1600 AD, it was known by the best.

Let us praise it and love it. Let's sound out the call. 0 lets us count high, or count nothings at all. We could not fly to space or make *Minecraft* to play. Without 0 in our numerals, we'd be nowhere today.

[MUSIC PLAYING]

MOLLY BLOOM: Wait. Do you hear that? It's time for the mystery sounds.

SUBJECT 7: Mystery sound.

MOLLY BLOOM: Here it is.

[MACHINERY WHIRRING]

EISHA: Is that related to math? Like, the sound?

MOLLY BLOOM: It's related to numbers.

EISHA: Numbers?

MOLLY BLOOM: Do you have any guesses?

EISHA: I thought it sound like a drill, like, going into the ground. Something like that. Like a drill.

JOE: Negative numbers? I don't know.

MOLLY BLOOM: Are good guesses. We're going to come back to that in a little bit so you can think about it, process it, see if any other ideas come up. Your sense of hearing is the most important one in trying to figure out what the mystery sound is, but some people experience two senses where most of us would only experience one. They're called synesthetes. So what color does a trumpet make?

JOE: I have no clue.

MOLLY BLOOM: How pointy does chicken taste?

JOE: I don't know.

MOLLY BLOOM: What personality does the number 3 have?

JOE: I'm not sure.

MOLLY BLOOM: Well, here's neuroscientist Edward Hubbard to explain.

EDWARD HUBBARD: Synesthetes, when they see normal, everyday sorts of things, like letters and numbers, or when they think about days of the week, will have additional unusual experiences associated with those.

RILEY VAN ARSDALE: Hi, my name is Riley Van Arsdale, and I'm from Bradenton, Florida. I'm 15. Pretty much all of the senses in my brain are intermixed. So I experienced more than one sensation to each stimulus. If I read letters, numbers, or words, and some names, I see them in color. And letters and numbers also have personality.

EDWARD HUBBARD: We know there are parts of the brain that are important when you're reading things. And those parts of the brain that are important when you're reading are right next to parts of the brain that are important for seeing colors. And so we think that synesthesia is a sort of crossed wires in the brain, where people see letters. And not only do they see the letters, but they also see the colors.

[MUSIC PLAYING]

RILEY VAN ARSDALE: It did bother me a little bit when I was younger when the colors of like 1 plus 2-- 1 is yellow, and 2 is blue when it didn't equal green because 3 isn't green. But I got over it. Doing homework, actually, it's quite helpful because I can remember a lot of mathematic formulas based on their color.

EDWARD HUBBARD: The first hint that we have about why this happens is that it runs in families. And this is a clue that it has something to do with genes.

[MUSIC PLAYING]

RILEY VAN ARSDALE: Three is my favorite number, so I feel bad kind of saying that because I feel like I'm going to make the other numbers feel bad. But three is my favorite number because it's a girl. And she's kind of sassy, but she's very outgoing and friendly.

Eight's kind of awkward because he has two sisters, and he doesn't really know what to do around girls his own age because both of his sisters are older than him. His sisters are seven and nine, and they're extremely protective of him. I like number two because he's kind of quiet, and he's kind of the nerdy one of the group.

I mean, I guess so is one, but two is really nerdy. I like to think I'm more like three, but there's definitely plenty of nerdiness on my side. So yeah, two and three are probably the most likely.

[MUSIC PLAYING]

EDWARD HUBBARD: Some synesthetes say, I never even thought about it. It's been this way for my entire life, and I didn't know that other people didn't do it.

RILEY VAN ARSDALE: I wouldn't have known it was different at all if I hadn't figured it out, I guess, is the term in fifth grade.

EDWARD HUBBARD: Then there are people who say that when they were, for example, in second grade, they said something about how Wednesday was a lovely pink word and somebody looked at them strangely.

RILEY VAN ARSDALE: I made some offhanded comments about how 35 was such a nice red number, and I was tormented by my classmates because I was a freak in comparison to them.

EDWARD HUBBARD: And they've kept this secret for most of their lives, thinking that maybe it's this horrible, deep, dark thing. And for those people, they're immensely relieved to learn that there's a name for what they're doing and that other people do it and that they're not alone and that they're not crazy.

RILEY VAN ARSDALE: I thought that it was something that I could get, like taken away for, like schizophrenia or something, so I just kept it a secret for a very long time. About last May actually is when I started dropping hints to my parents, and eventually, I just came out and said, hey, numbers have color, and we googled it.

[MUSIC PLAYING]

EDWARD HUBBARD: We were actually told that synesthesia was really uncommon. The estimates were as low as 1 in 20,000 people. And then more recently, Julia Simner and Jamie Ward have done an eye study where they measured synesthesia in everybody that walks through the door of the London Science Museum.

And they found that it was perhaps even 1 in 100 people that had colors for letters and numbers. And if we look at all the different types of synesthesia, it might be as much as 5% of the population that have some form of synesthesia.

RILEY VAN ARSDALE: I definitely want the kids to know that it isn't something to be ashamed of or afraid of at all. And I also want other kids who don't have it to not be so aggressive towards it because it's not something that makes them weird. It's not something that makes them freaky or anything. It's just another oddity.

[MUSIC PLAYING]

EISHA: That was Riley Van Arsdale from Bradenton, Florida. She's 15 years old, and she's currently in college. And that was Edward Hubbard, educational neuroscientist from University of Wisconsin-Madison.

GIRL: Shh. Mystery sound.

MOLLY BLOOM: So we're going to hear one more time.

[MYSTERY SOUND]

OK, so any guesses?

EISHA: Infinity?

MOLLY BLOOM: Infinity? Actually, it's a thing. We actually have a hint from someone who knows what it is.

JOE SHOOT: It has to do with athletic wear, decorates jerseys.

MOLLY BLOOM: Does that give you any other ideas?

EISHA: Is it the machine that puts the numbers and letters on the Jersey?

MOLLY BLOOM: Yes, you are right, and we actually have someone to explain what it is. It's Joe Shoot from Gemini Athletics.

JOE SHOOT: We manufacture hockey jerseys from scratch completely custom. The step first is we will cut the fabric and sew the jersey. And then the next step is decorating the jersey with the machines that put the letters and numbers on it.

We use an 8 head embroidery machine and a 4 head embroidery machine. It does 800 stitches per minute. So you can do a full number in just a handful of minutes, probably three minutes tops.

It's got the needles on it. It's got bobbins. So it essentially has all the components of your at-home sewing machine. It's just a little faster and a little more efficient.

[MUSIC PLAYING]

MAN: (SINGING) Efficient, logical.

MOLLY BLOOM: You guys know what infinity is?

EISHA: I think it's kind of-- it's not really an imaginary number. It's a number that goes like on and on that doesn't really have an ending point.

MOLLY BLOOM: Yeah, so basically, it's not a number, but it's a concept. So it's the idea of endlessness, something that goes on forever, like you were saying. And we could say the alphabet and get to the end pretty quickly, but we could start counting right now and never ever get to the end of numbers. We'd be counting forever.

MAN: Forever.

EISHA: 1--

MOLLY BLOOM: 2--

JOE: 3,

EISHA: 4--

MOLLY BLOOM: And there are actually a couple different kinds of infinity. There's countable infinity. And that describes the infinity of whole numbers like 1 2, 3, 4, 5, et cetera, et cetera. And there is a set order that they go in, and you know what comes next.

JOE: --93--

EISHA: 94--

MOLLY BLOOM: 95--

JOE: 96--

EISHA: 97--

MOLLY BLOOM: 98. Same goes for fractions. You could make a list of all of the fractions like 3/5, 7/8, 12/15. And that list would also go on forever, but at least you could make a list.

EISHA: 1,245,800--

MOLLY BLOOM: 1,245,801--

JOE: 1,245,802.

EISHA: 1--

MOLLY BLOOM: The other kind of infinity is uncountable. So that deals with numbers, with decimal points, like pi. So we talked about pi earlier. And that's an irrational number, meaning that it doesn't correspond with any fraction. It goes on forever.

MAN: Forever

MOLLY BLOOM: If you tried to put all of these kinds of numbers in a list-- the ones with long strings of numbers after their decimal points-- you simply couldn't. And because you can't, this means that the infinity of decimals is actually bigger than the infinity of whole numbers or fractions. That means there's more numbers between one and two than there are if you kept counting forever.

Is your brain hurt?

JOE: A little bit.

EISHA: A little.

MOLLY BLOOM: Yeah, mine too. And we have more about this on our website, brainson.org. But Steve Gregoropoulos wrote a song for us about infinity. So Eisha--

EISHA: Mm-hmm.

MOLLY BLOOM: --what is the symbol for infinity? Can you tell us?

EISHA: It's an eight on its side.

MOLLY BLOOM: You could do a dance where you just trace an eight on its side forever into infinity.

MAN: Forever.

[INDISTINCT SINGING]

STEVE GREGOROPOULOS: (SINGING) Infinity, infinity, infinity. Infinity, infinity, infinity, infinity.

Infinity, I love you forever. And I love every little thing about you.

There is so much time, and there are so many things about you to love. You can count forever, and you will never ever reach infinity. You might think that it's the biggest number you can find.

CHOIR: (SINGING) Well, it isn't really a number. It is endless, less. I hear something that will really blow your mind.

STEVE GREGOROPOULOS: (SINGING) You can put a decimal point right after that one. And then you can count forever, and you will never ever get to two.

CHOIR: Stretching out forever, there is more than one infinity. Endless things are [INAUDIBLE].

[MUSIC PLAYING]

STEVE GREGOROPOULOS: (SINGING) If you take the infinite numbers that you use when you are counting plus the endless tiny fractions like the ones between one and two, you will get a set with both infinities in it that is infinitely larger. But my dearest children, that is still less than I love you.

CHOIR: Infinity, infinity, infinity, infinity. In the infinity of time, which is not a number.

MOLLY BLOOM: We could go on and on about infinity. But let's get back to a number, an irrational number. Pi, anyone?

EISHA: 3.141592653589--

WOMAN: All right, cats. Listen up. This poem is called pi.

Pi, Oh, pi. The apple of my eye. You are an irrational number. That means you have no end your numbers, man.

They go on in like an infinite manner. Now some pies are sweet, some pies are made with meat. But in the math world, pi is always the exact same number. It comes from taking a circle round, man.

Think like an apple pie. And measuring the circumference of that circular shape. Now for those of you who aren't in the know, the circumference is the distance around the circle, you dig?

So you take that circumference, and you divide it by something called the diameter. Now cats, the diameter is just the distance from one end of a circle to the opposite side. Like imagine you cut a cherry pie right in half right down the middle and measured the length of that half pie slice?

Well, that would be your diameter, cats. So like I said, you divide that circumference, the distance around the circle, by the diameter, the distance from one end of the circle to the opposite half. And like mathematical magic, you get a number. That number is pi. And it's spelled just P and I.

And here's the thing, cats. It's always the same no matter the size. Your circle could be tiny or as big as the sky.

If you divide that circle's circumference by its diameter, I do not lie. It's always the same pi. And here's the number I'm talking about, cats. It's 3.14159, but it doesn't end there. It goes on 2653589, a never-ending decimal parade of numbers so groovy, 793238462.

You can read them on and on till your face turns blue like a blueberry pie. This number is infinite, man. It goes on forever.

It's irrational, man. It never repeats. And it is so heavy, cats. That's pi, you dig?

[CLAPS]

MOLLY BLOOM: Woo. That's it for this episode of *Brains On.*

EISHA: This episode was produced by Molly Bloom--

JOE: Marc Sanchez--

EISHA: And Sanden Totten.

JOE: With help from Levi Weinhagen--

EISHA: Judy Osberger multiplied by David McMayor--

JOE: Plus or minus the square root of Judy-Ann Ehrlich--

EISHA: Divided by Steven Gregory--

JOE: Plus Barbara Guastafero to the Ashish Agarwal power--

EISHA: Equals many thanks.

MOLLY BLOOM: Any questions or ideas? We'd love to hear from you. Write to us at our website, brainson.org. While you're there, you can learn more about this episode, like infinity and synesthesia, and download past episodes. You can also find *Brains On* in the iTunes store.

MOLLY, ISHA, AND JOE: Thanks for listening.

CHILDREN: *Brains On.* Woo-hoo. Whoo.