But Why: A Podcast for Curious Kids

Why Don’t Bicycles Fall Over?

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[Andy Ruina] That's a great question. I like it. I've liked it for my whole life, and I still think it's a great question.

[Jane Lindholm] This is *But Why: A Podcast For Curious Kids* from Vermont Public Radio. I’m Jane Lindholm. On this show, you ask the questions and we find the right people to help answer them.

It’s summertime, at least in the northern hemisphere. For most of you, school is out, and you're having some long, lazy days. I hope that means you're finding time to get outside and ride your bike. Later in the show, we're going to hear from someone who liked riding so much she has made it into a career. Lea Davison is about to compete for the United States in the Olympics as a mountain biker. But for most of us cycling is just a hobby. When you're learning to ride, the real hurdle to getting confident is figuring out how to balance on two wheels, and the mysteries of balancing got one of you curious enough to ask this question.

[Ryland] Hi, I’m Ryland. I come from Underhill, Vermont. I’m four years old. I want to learn about why bicycles do not fall over when they're going straight or leaning around the curve but they do when they're stopped.

[Andy Ruina] Hi, Ryland. I’m Andy Ruina.I'm 63 years old, and I live in Ithaca, New York, where I teach engineering at Cornell University.

So I'm a teacher.

[Jane Lindholm] Professor Ruina says he became interested in this question at about the same age as Ryland.

[Andy Ruina] In fact, I found a note that my mother wrote about me when I was four years old.

And I asked her or somebody — I asked, “Why does a top stay up when it’s spinning and not when it's not spinning?”, which isn't quite exactly the same question you're asking, and it has a different answer than your question, but I've been wondering about things like that since I was your age.

[Jane Lindholm] Let's get to the answer, but I'm going to warn you it's a little bit complicated.

[Andy Ruina] The reason it's a good question is because some things you sort of think should fall over and some things you sort of think shouldn't fall over.

If you look at a glass on a table and nobody's shaking the table, you think that shouldn't fall over. Or you look at the table; you don't think it's going to fall over. Or if you look at a box on the floor, you don't think it's going to fall over. Or if you look at a lamp hanging from the

ceiling, you don't think it's going to fall over. What are the things that you think would fall over? The things that you think would fall over are things that aren't really held up in a very broad or very wide way at the bottom. Like if you take a broom or a mop and you take the head of it and put it up and put the handle on the floor, and you try to balance it, that falls over.

Or if you take a needle or a pin and try and stick it up, it falls over. Or if you take a toothpick and put it on the ground or a table, it falls over. If you take tall things and you just support them on a point or you support them on a narrow line, they fall over. A bicycle is really that kind of thing. Imagine that someone's riding a bicycle and — maybe they're not riding a bicycle, maybe the bicycle's still or is moving, and you are right behind them. If you're right behind them, just straight behind them, it looks like the bicycle's balanced on a point because the two wheels are one in front of the other, and there's nothing to keep the bike from falling over sideways. That's the way brooms are and needles and pins and the things that you think fall over. There's nothing to keep them from falling over sideways. And then why do they fall over sideways? It's because if they just tipped a little one way or another — and they're always tipped a little one way or another — and gravity is pushing down and the ground is pushing up, and those two pushes are not lined up with each other, and it makes it turn over. Say if it's leaning to the right, gravity pushes it more to the right, and the ground force — or the where the ground is touching it on the left — that pushes it over. That's why things fall over. It's because if they tip a little bit, there's nothing to hold them up from falling over. The gravity force pulls them over.

[Jane Lindholm] Gravity is the force that makes things fall to the ground if we drop them.

[Andy Ruina] The thing that's really maybe the easiest to understand is, say, a person standing up. A person standing up, they have big feet and so you say, "They shouldn't fall over because their feet are big and that keeps them from tipping over." What about a person who's standing on stilts? Do you know what stilts are? Stilts are these sticks, and people walk around on stilts, and they're just little sticks. There are only about an inch across at the bottom. If somebody's standing on stilts, they basically can't stand still because if they did they'd fall over like a broom or a needle or a toothpick or any tall, narrow thing. What do people do when they're on stilts? When they start to fall they take a step, so they move the support point over to the side to keep them from falling. And that's what happens on a bicycle, too, though it's a little hard to see it, so I'll try to give you the picture of it. If you look at a bicycle from behind when someone's riding a bicycle — so you're looking at them from behind — and imagine they start to fall to the right, and the bicycle's leading to the right. What they have to do is move the wheels to the right to keep them from falling over. They want to take a step with the wheels, but you can't take a step on a bicycle. What happens is the person on the bicycle turns the handlebar to the right, and, because the bicycle's moving forwards, when they steer the bike to the right it moves the wheels to the right. So it moves where the wheels are touching the ground back underneath the person and they can balance. So, just like when you're on stilts and you fall to the right you take a step and you move the place where the feet touch the ground or the stilts touch the ground under the person, when a bicycle falls to the right the person steers the bike to the right, it moves the wheels under them to the right, and then they're held up from underneath where their weight is and they don't fall over. If a bicycle is not going forwards, you steer to the right and it doesn't move to the right at all because the bicycle — it just turns the wheel and the wheel just sits there in place. So what's the thing about a bicycle moving is that when a bicycle is moving it makes it so that when you steer the bicycle — you turn the handlebars — it moves the tires sideways. You think of steering the bicycle as causing it to go in corners, but really the main thing steering does is it

balances the bicycle because on a moving bicycle when you steer it, it moves sideways. Now you might wonder about that maybe it's because the wheels are spinning or maybe you're wiggling your body to keep it up, and maybe it's because it's going forwards, and some people will say momentum keeps the bicycle up, and all those things are nonsense. And the way you can prove that they're nonsense is you can take a bicycle and you can tie up the steering with rope so you can't steer it. Then you get on the bicycle and somebody pushes you to get you going forwards and you know what you do? You fall down, and there's nothing you can do about it. If the bicycle can't steer, the bicycle can't stay up, and if the bicycle's not moving, it can't stay up either.

[Jane Lindholm] Actually, he says some really talented circus performers can stay up without moving forward, but that's because they are steering or balancing with their bodies. Sometimes you see bikers stopped at traffic lights who appear to be staying upright without moving. That's called a "track stand". Professor Ruina says they're actually moving forward and back and using the sideways motion of the wheel to balance, but for the rest of us it's the mix of going forward and steering that balances the bicycle.

Want to try a balance experiment to illustrate the principles Professor Ruina was explaining? Go grab a broom. Put the end of the stick of the broom in the palm of your hand, the top of the handle, so that the bristles of the broom are straight up in the air. Now try to balance the broom. You might have to move your hand around to keep it balanced. Maybe you should try this outside. If the broom starts to tilt over to the right, move your hand to the right and see if you can get the broom to stay up. If the broom starts to fall to the left, you move the palm of your hand to the left, right underneath the broom. See if you can get the broom to stay upright by constantly shifting your hand underneath it to keep the balance just right.

There's another question that Professor Ruina has spent a lot of time thinking about: How can a bike balance itself even if a person is not on it? Not when the bike is standing still — we already learned about that — but if you push a bike forward so its wheels are spinning but there's no one actually riding it or keeping it balanced, the bike can still move forward and stay upright. How does it do that?

[Andy Ruina] The simple answer is for some complicated reason the bicycle has built in it various things that make it steer to the right when it's falling to the right. So it makes it so that the wheels go back under the bike when it's falling to the right. And that's so complicated that we wrote a paper — that's like a story where scientists do in their work in universities; they write these things called papers which are stories for other scientists — and basically the story was that we think that's so complicated that nobody will ever understand it. So we worked so hard to understand it, and we couldn't do it. We think nobody ever will understand it. So I can tell you a lot about it, but, basically why exactly a bicycle, all by itself, turns the right amount, is kind of a mystery.

[Jane Lindholm] Want to see a video of a bike without a rider? We have a link to Professor Ruina's YouTube video up at the But Why Facebook page. So now we know how a bike stays up when you ride it. But how does the bike actually work? What makes the wheels spin? What's the chain for anyway?

[Kevin Rose] I'm Kevin Rose and I manage the Trailside Center for Local Motion, down on the waterfront in Burlington, Vermont.

[Jane Lindholm] Local Motion is a group that promotes safe cycling.

[Kevin Rose] Actually one of the things that's always attracted me to the bicycle is it is so simple. It's one of the simplest and actually one of the most efficient machines known, just in terms of the amount of energy that it takes to move something through space. There really isn't much that's more efficient than a bicycle. Bicycles today really don't look that much different than they did, say, 100 years ago, with the two wheels, the frame, the handlebar, the pedals, the crank — which connects what's known as a chainring to the rear wheel on gears on the rear — and the rider by spinning those cranks moves the bicycle forward. And of course we don't want to forget the brakes when you need to come to a stop.

[Jane Lindholm] So how does it work? Let's start by picturing the bike.

[Kevin Rose] You're seated on a seat, hands on the handlebars; your feet are on the pedals.

You're turning the pedals around. The pedals are connected to what's known as a crank, which is turning what's known as a chain ring, which is a large sprocket up front that is connected to the rear wheel with a chain, and that chain is driving the rear wheel of the bicycle. So the rear wheel has another sprocket or quite often it will have a few of them which allows you the ability to pedal up hills or fast on the flats or downhill so it allows you to change speeds, essentially. It's a front sprocket, the one that is pedaled, that's connected to a rear sprocket on the wheel, and the chain connects the two and drives the whole thing around.

[Jane Lindholm] So when you pedal you're turning the chain ring. That's the circle thing that looks like it has teeth on it. Those teeth move the chain which moves the back wheel. If you shift your front gears, you're moving to a different chain ring and that determines how fast you have to pedal to turn the wheel. The rear wheel also usually has a few gears you can shift into and out of. Those are helpful when you're going up and down hills, but most of us start out on bikes with no gears, and when bikes were first built they were even simpler.

[Kevin Rose] Back when the early days of bicycling, if you've ever seen pictures of bicycles with a very large wheel on them, it was sort of like the tricycles today, where the pedals are attached directly to the wheel. It was known as a direct drive, and in order to go faster you needed a bigger wheel. In other words, when you turn that wheel one revolution a larger wheel goes further than a smaller wheel. So if you wanted to go faster your option was a bicycle with a bigger wheel.

It wasn't until about 130 years ago that the first bicycle that connected the sprocket up front to the wheel was introduced. It was actually called a safety bicycle. And, I don’t know, maybe it was because the bicycles were so high, those high wheelers, that the safety bicycle got you lower to the ground. But anyhow the chain allowed you to have a larger sprocket up front and a smaller sprocket on the rear to effectively make the wheel the same size as that large-wheeled bicycle. So rather than having a large wheel you had a large sprocket up front driving a small sprocket in the rear, and it allowed you to go faster.

[Jane Lindholm] Kevin says he fell in love with bikes when he was a kid because of the freedom it gave him to explore his neighborhood. I hope all of this talk about bicycles has made you want to get out and ride. Maybe you don't know how or you're just learning. Everyone has to start somewhere, even the best in the world. Lea Davison is a

professional mountain biker. In fact she's competing in the 2016 Olympics in Rio de Janeiro, Brazil. This is her second time representing the United States at the Olympics, and she stopped by to show us the best way to get on a bike and get going without falling.

[Lea Davison] So you have to swing your leg over the saddle, and so then you're just standing over — you're straddling the bike —

[Jane Lindholm] Saddle being what many of us would call a seat.

[Lea Davison] Yes, a seat, exactly. And then you want to make sure to get going so you can get going before — and you don't want to fall — so you bring one pedal up to what we call the power pedal position. So, if your pedals were like that the arms of a clock, one pedal would be at the twelve o'clock - one o'clock position, and then you put your foot on it and you want to push down on that so you have momentum and speed when you're going.

[Jane Lindholm] Then what do you do?

[Lea Davison] So then you either sit on the seat or stand up in what we call the downhill attack position. So you stand up off your saddle, you bend your elbows and knees, and you put your pedals level to the ground. So, again with the clock reference, if your pedals were arms of a clock, they would be at three o'clock and nine o'clock. So that way your pedals don't hit any roots or rocks and you can safely go over obstacles.

[Jane Lindholm] So you're basically standing up like you would on the ground, like your feet are sort of in the same position.

[Lea Davison] Exactly. Exactly. And that's the best way to go downhill or to go over obstacles. If you're climbing, you can be seated, and you're pretty much just pushing down hard on the pedals.

[Jane Lindholm] When you're climbing, how do you want to shift gears so that you can make it the most efficient way to climb?

[Lea Davison] Yeah, so before the climb you want to make sure to shift to an easier gear or maybe your easiest gear so that way you don't get halfway up the climb and you can't pedal anymore.

[Jane Lindholm] What about protection? You should always wear a helmet.

[Lea Davison] Always, always wear a helmet. Even if you're on a bike and you're pedaling at ten feet then you should have a helmet on.

I just love being outside.

And when you mountain bike you get to ride single track in the woods and it's the best way to be outside. And also when you ride a bike you get to see a lot. So you get to go further than if you run and you get to go fast. So that's why I love mountain biking.

[Jane Lindholm] Some people are afraid, like me, a little bit afraid of going fast downhill on a bike over roots and rocks. How do you get over that fear?

[Lea Davison] I think it takes a progression.

So you just slowly ease into it. So you start by going off the curb of a sidewalk or you start by going over just a little rock and then you build up to bigger rocks, bigger roots. You don't have to do it all at once. You just ease into it.

[Jane Lindholm] What's it like to go to the Olympics? This will be your second one, right?

[Lea Davison] Mm-hmm. The Olympics is everything that it's cracked up to be and more. It really is — I mean, it sounds cliché — but it is a dream come true.

And everything about it is just such an incredible experience, from meeting different athletes in the Village. You never know who's going to walk in the elevator in the Team USA housing. It could be Michael Phelps, it could be Missy Franklin, anyone. Just from having the support of your entire hometown or the state of Vermont and representing your country is really something that most people don't get to experience, and it's an incredible thing.

[Jane Lindholm] So many kids want to be professional athletes, and maybe it's, ”I want to be in the NBA,” or “I want to be a professional baseball player,” or “I want to go to the Olympics.” And you kind of need that drive to make it happen. But there are also a lot of adults in our lives who are like, “Oh, that's a nice dream, honey, but why don't you set your sights on something that's more reasonable?” But you've made it happen. So what's your advice to kids who at age five or eight or 10 are saying “No, this is what I think I want to do and I want to be an athlete and I want to make it happen”?

[Lea Davison] Yeah. You can make it happen. My advice to kids — I was that same kid with the dream of going to the Olympics, and when I was a kid, I thought it was going to happen with downhill ski racing. So it just takes a lot of hard work. You just need to work very hard but you can set your mind to anything that you want to do.

[Jane Lindholm] That was Lea Davison. She's one of three people representing the United States in mountain biking in the Rio Olympics. Her events are at the very end of the games in the last two days. Good luck, Lea. And that's it for this episode of But Why. We'll be back in two weeks with a show all about bugs.

We'll be hearing about bumblebees, mosquitoes and ticks, and we'll be joined by a couple of women who call themselves The Bug Chicks. They have devoted their lives to showing us all the wicked cool things we can know about bugs.
As always, if you have a question about bugs, bikes or anything else, let us know. Have an adult help you record your question on a smartphone. Tell us your name, your age, and where you live.

Then send the question to questions@butwhykids.org. We have received so many questions. We can't answer them all, but we are working our way through them, and we love them, and we hope you're enjoying the podcast.

But Why is produced by Melody Bodette and me, Jane Lindholm, at Vermont Public Radio. Our theme music is by Luke Reynolds. We'll see you again soon. Stay curious.