How the bicycle got its spokes

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Credit: Image courtesy of Rachael on Flickr

The humble two-wheeler is a miracle of engineering. But just how did we get from the Penny Farthing to Kevlar tyres?

The evolution of the bicycle is a glorious story of serendipity and ingenuity. It didn't just require technological advances and engineering knowhow: its history touches on all kinds of accidental coincidences, from volcanic eruptions to an early roller skating craze. Like all great inventions, it required the right people to be in the right place at the right time. And like most good machines, it is both simple and phenomenally complicated.

"No matter how much we try, it's very difficult to get away from the beautiful elegance of the double-diamond frame and its conventional equipment," says Professor Tony Purnell, Royal Academy of Engineering Visiting Professor at the Department of Engineering and head of technology at British Cycling. "Take the chain. As a commuter, the chain is greasy, it's a pain, it gets muck on your clothes. As a racer, a chain is 98.5% efficient, weighs 200g or so and that's all that counts. It's awfully difficult to get any alternative close to that."

It's true that we never forget how to ride a bike. But it's also true that most of us don't know how we do it in the first place. The Bradley Wigginses of the world excepted, there are usually only two occasions when we consider the forces required to drive a bicycle: once, aged four and desperate for freedom, and again, maybe 20 or 30 years later, working out how to help our own four-year-old develop that elusive, lifelong balance. And even then, it's not something we consciously think about. We don't consider the complex mathematical parameters.

We just fall off, or not.

But this is how it should be. "People are almost shocked when a bicycle goes wrong, because it's such a reliable piece of kit, especially when stripped down to its essentials," says Cambridge alumnus Matt Seaton, staff editor at the New York Times, former Guardian cycling columnist and author of three books on cycling. "It needs incredibly little maintenance. There is a beautiful simplicity and a magical efficiency.

The chain drive is a really simple technology but it is fantastically efficient at transmitting the power that you put in at one end into an output at the other."

Pedalling, for example, is simple. When you push down with your feet on the pedals of a modern bicycle, the force causes the chainring attached to the pedals to turn, and generates tension in the chain. This tension is transmitted through the chain to the cog on the back wheel, which causes the back wheel to turn. The back wheel pushes backward on the road. The law of action and reaction means that this force pushes the bicycle and its rider forward.

Then comes the phenomenally complicated bit: not falling off. "Only a few people really understand how balancing a bicycle works," says Philip Garsed, a PhD student in electronic engineering whose passion for bicycles developed into his recent talk at the Cambridge Science Festival, titled How the Bicycle Got Its Spokes. "There are lots of effects interacting with each other. One of the most interesting is the gyroscopic effect. If you have a wheel spinning around an axle and then try to tilt the axle from side to side, you get this weird effect that makes it resist that change. On a bike, that tends to keep you upright and for quite a long time it was thought that this was the reason why a bike can be balanced. It was then proved that it was not actually necessary – someone stuck a flywheel that rotated in the opposite direction on to the wheel and eliminated the effect, but the bike was still rideable. I have a book that explains the details of bicycle balance. It's hundreds of pages thick and it helps to have a physics or engineering degree to get your head around it."

Yet bicycles were originally born of a simple need: transportation that did not require feeding. In April 1815, Mount Tambora on the island of Sumbawa, Indonesia, erupted. It was the biggest eruption ever recorded. It sent vast quantities of gas, dust and ash into the atmosphere, forming a global fog that blotted out the sun and caused temperatures to fall. In Europe and North America, 1816 became known as "the year without a summer". Snow fell in August and crops rotted in the fields. The people starved.

This led Karl Drais, a German inventor, to ponder the problem of horses.

They were the only practical way to get around. But you had to feed them, even if you weren't using them. Wouldn't it be better to have a form of transport that didn't use up scarce and precious resources? He came up with the Laufmaschine (running machine). "Well, it was bicycle-like," says Philip. "It was not very refined. It was made of wood. But the big leap forward was that it had two wheels, one in front of the other, and a seat, fairly close to the ground. There was no easy way of stopping it, as it had no brakes." This aspect of the wooden horse was enjoyed tremendously by its young riders, but not so much by the authorities in various cities, from New York to Hull, who banned it on safety grounds.

There were clearly problems with the wooden horse. It could not be controlled. There was no way of propelling it, apart from getting your mate to drunkenly launch you down a hill. But for the next 45 years, nothing much happened, until one significant problem – propulsion – was solved, with the help of roller skates.

It's always deeply satisfying to look back at theories that turned out to be spectacularly wrong (the anti-railway idea that humans would suffocate if subjected to rapid motion, for example), and the overturning of such a belief made the next step in bicycle evolution possible. "Previously, it had been widely thought that it would be impossible for a person to keep control whilst riding on wheels without having one's feet on the ground," says Philip. "A brief roller skating craze, it has been suggested, proved that wasn't the case, and then three Frenchmen – one carriage maker and two blacksmiths – came up with the pedal. Shortly afterwards, a guy called James Starley, who was from Coventry, came up with the idea of making wheels held in shape by weaving wire spokes together. He worked out a way of doing that which has been used ever since. Spokes on a bicycle wheel are pulled very tight and this makes spoked wheels both strong and very light."

Enter (slowly and carefully) the Penny Farthing. It's hard not to look at it these days and wonder: "What were they thinking?" But in fact, Philip points out, the wildly oversized front wheel was eminently logical for a bicycle with pedals attached directly to the front wheel, and lacking those other yet-to-be-invented components: gears and a chain. With no gears to control how far the wheel turned with each pedal stroke and therefore increase or decrease speed that way, the only way to go faster was to make the front wheel bigger and bigger. Happily, some riders possessed models incorporating a spoon brake – a lever on the handlebars that pushed a leather or metal pad against the front wheel.

Tyres remained solid rubber – until John Boyd Dunlop's three-year-old son became ill and was prescribed exercise. Dunlop bought him a tricycle, but the cobbled streets of his native Belfast plus solid rubber tyres did not make for a comfortable ride. Dunlop experimented with rubber and discovered that a tyre filled with air did a far more efficient job. Around the same time, James Starley came up with his 'safety bicycle'. His big idea? To remove the pedals from the front wheel and instead use a chain to allow them to drive the back wheel, without being directly attached to it. This made it practical to create a much safer bicycle with two equally sized wheels front and back. The Penny Farthing became obsolete almost overnight and the bicycle as we know it today was born.

But it's never stopped changing. We just can't leave it alone. There's a multitude of potential modifications whirling around that simple double-diamond frame. "A century ago, there was a mechanical revolution," says Michael Sutcliffe, Reader in Mechanics of Materials at the Department of Engineering, who oversees the Bicycle Design Project module. "And over the last 40 years, we've seen a materials revolution, which began in the aerospace industry and is now feeding into bicycles. This isn't a new thing – the Wright brothers were originally bicycle engineers."

And what materials. Aerospace aluminum alloys and carbon fibre composites for frames and wheels are the norm now, replacing the steel of old. Saddles previously made in leather are now plastic composites and foam. Kevlar is used in tyres, and different kinds of steel and titanium alloys in spokes and chains.

"I come from a Formula One background, and we pride ourselves on being leading edge in composite materials," says Tony Purnell. "Coming to cycling was a bit of a wakeup call. The construction of the bikes is really pretty impressive and it's certainly, in some cases, the same standard as Formula One. But the incredible thing about cycling is that they make thousands of them at a price that people can afford. Which is certainly not the case with a Formula One car."

And following the stunning success of the British Olympic team, there's now an even bigger challenge ahead for bicycle engineers. How do you improve on near-perfection? Purnell points out that the huge gains made from new materials and aerodynamics over the last decade or so are starting to plateau. "It was virgin territory. When you apply science to a new area, you get big gains very quickly. We are not there any more. It's easy for any cyclist to buy top-end equipment and clothing and the difference between standard off-the-shelf and the very best Olympic equipment will be quite small in terms of technology-led gains; disturbingly small. So we have to think far more laterally now about how to gain advantage."

All the talk now is of the complex: aero-dynamic tweaks, aero-helmets with built-in visors that smooth the front of your face and teardrop-shaped, super-light bike tubes developed in wind tunnels and using finite element stress analysis. It's all a long way from the Laufmaschine or, indeed, that four-year-old finally breaking free from her stabilisers.

But these conversations aren't just happening in Tony Purnell's so-called

Secret Squirrel development team, deep in a British Cycling bunker. Such is the popularity of bicycle science, ideas and conversations are happening all over the internet, in school playgrounds, in bike shops and between engineering cyclists around the country. Luckily, if you care not a jot for the science, it doesn't matter. Today you can still just get on and ride the most fantastic bikes.

As Mark Twain concluded after finally mastering his machine: "Get a bicycle. You will not regret it, if you live."

Provided by University of Cambridge

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