

Welcome to *Entanglements*

genetically modified meant. The narrative exploited ignorance and sort of fueled people's fear of this whole thing. So I think that's why the scientific community felt we need ambassadors to try and give people an informed insight into what the science is, and then they can start to make their decisions. They may decide still to ban genetically modified crops, but let's do it in an informed way, not an ignorant way.

Noah: Completely, and it's so interesting looking back over the last 20 years, conversations twisted and turned.

Prof du Sautoy: Still turning, yeah, exactly.

Noah: If we look back on the history of science, the history of modern science, however it's twisted and turned itself, scientific progress has seemed to many people, and still seems to many people, a discovery, and then from discovery comes dominion. Francis Bacon talked about inquiring into the womb of nature and becoming dominion over it. I'm really interested in how maths has viewed science in such a way, if it's viewed science in such a way, or is it simply the apple which falls on the head and that's it?

Prof du Sautoy: Yeah, you know, mathematics grew out of humans' attempts to navigate the environment around them. For example, if you could spot a pattern in nature, things to repeat themselves, the way the Nile would rise and fall, making predictions about that would help a farmer to decide whether to take the crops in or to plant seeds this year.

So I think very early on, humans were using a kind of mathematical approach to the world to give themselves an advantage. In some ways, I would define mathematics as almost the science of patterns. And that ability to read a pattern into data from the past and project it into the future gave humans who could do that a real edge. I sort of feel that mathematics did emerge out of humans' attempt to understand their environments and things like my own subject of symmetry. The human brain became very sensitive to symmetry because that was generally a sign of something significant happening in the natural world. You know, the chaos of the jungle, if there's something with symmetry, that's likely to be an animal. It's either going to eat you or you can eat it, so you become hypersensitive to picking out those signs of symmetry.

But one of the things that's interesting is that certainly mathematics first emerges out of

But I do think you start to see a kind of interest in just playing with the structures that are emerging from this in their own right, for their own fun. I think what's interesting, because mathematics, as you go through history, it seems to be very unclear what the practical application of this is. And I think that's what's exciting, deciding to generate maths, just in a sense for the joy of investigation. But what often then happens is that the maths, it takes off, it goes up into the intellectual stratosphere, and then weirdly you'll find it lands back down again, much later on with an application that the mathematics that we developed independently of the physical and the natural world suddenly has a massive impact on being able to make new technology or understand something we didn't do before.

And I think that's what's fascinating this kind of dialogue. There is something separate about mathematics from the natural world, yet because it emerged from the natural world, it necessarily has the potential to have a big impact back again.

I did a very interesting program about artificial intelligence for the BBC a few years ago. And at that time, there was a real movement for artificial intelligence to be embodied. It felt that our intelligence was very much about our embodiment, our senses, how we interact with the world. And a lot of AI researchers are saying, look, we cannot create an intelligence which is separate from the physical world around us. This person made an interesting challenge to me. He said, I don't think there's any mathematics that you've created that doesn't have some genesis in a physical embodiment. And I thought that was interesting because in some ways I spend my time so physically unembodied in my mathematical work that I felt, oh no, everything's in the mind and I don't need the physical world around me to actually create my mathematics. I thought, you know, something like the square root of minus one. There is no physical distance which when you square it gives you minus one. So where is that?

Actually when I thought about it, it was a really interesting challenge because where did the square root of minus one come from? It came from this idea of, yeah, okay, if you have an equation, $x^2 = -1$, is there a solution to that? And that actually came out of questions of, well, what if $x^2 = 2$? $x^2 = 2$, that means x is a square root of two. And one of the things the ancient Greeks discovered was that the square root of two is not a number you can write as a ratio of two whole numbers. It's called an irrational number.

So already these equations were starting to create numbers which were quite a challenge to the physical world around us. I mean, we go into the very interesting question about, is anything in our physical, natural world actually representing the square root of minus one? Because then as a rational number, it's got an infinite decimal expansion, and quantum physics kind of cuts things off in a very finite way. So already raT24f I1 0 0 1 5 inciet the square

So that square root of minus one came out of the challenge of trying to solve equations, which actually came out of trying to measure things in our physical universe to make stuff. I thought that was an interesting challenge. Maybe we as mathematicians will never be able to access that because it doesn't have some sort of origins in the physical world which is what we need to start our intellectual journey.

Noah: Really interesting there. Implicitly you've been talking about this move from participation in the natural world to becoming an observer, moving away from, okay we are part of nature to, we are the observers of nature. I think part of that is also how humanity has tried to define itself, saying, okay, we're part of nature, actually, maybe we want to be a bit more, or we want to be a bit special, and we can come up with these concepts.

And I think it's really interesting how you talk about engaging a new language of mathematics, almost a musical language, that it's based in this reality and it moves up according to the scales, and it falls, it rises, and comes back to reality, and all the emotions implicit in that. But of course, when there's music, there's someone playing the music. And I think it's really interesting, this relationship between us, nature, and mathematics. Do you think mathematics itself, so-called pure mathematics, if there is such a thing, does it distinguish between us and nature? Or are we just part of the big symphony?

Prof du Sautoy: I think one way to explore that is to say, if I took humans out of this equation, would there still be mathematics? There's a big argument, philosophically, and a lot of people feel that the human is necessary to create that kind of language and that structure and the insights, but I really disagree with that.

My feeling is that, yeah, certainly the sort of mathematics and the stories we tell is very intimately related to being human and particular periods in history. I mean, I explore that in my books, how a period of history can actually be the trigger for new discoveries, because somehow the intellectual environment is encouraging. If you look at Newton - and Leibniz - time, what's happening there, it's the Baroque period, it's about art in flux, it's about people falling off horses, it's about movement through a building, curves

Now this comes actually to something quite fundamental about my view of mathematics and its relationship to the natural world. First of all, as a scientist, why do you keep on discovering so much mathematics bubbling underneath the natural world and helping us to explain things? You know, fundamental particles, it could have been a complete mess. And there was a period in the 1950s when scientists got very dismayed that it seemed to be just like biology, just like random, you know, why have we got cats and not unicorns? But then suddenly you make sense of all of these particles as facets of some strange symmetrical object and you can make predictions for new particles because they were missing things. You know, the unreasonable effectiveness of mathematics, as Ligna said, you know, why is there so much mathematics?

And it's my feeling that one has to turn this around. That mathematics, as I said, you know, prime numbers are there without us having to be around to notice them. But actually you don't need a physical universe even to have the property of a prime number. You don't need stones in order to have that. It seems to be something about the structural relationship. And for me, another definition of mathematics is it's the study of structure. And anything that's important will have structure there, and therefore will have mathematics.

But you see, mathematics for me doesn't need a moment of creation. The physical universe does. We talk about the Big Bang. We say, oh yeah, but what happened before the Big Bang? Maybe there was something. Maybe it's cycles of time, we talk about matter being produced by quantum physics, quantum fluctuations give rise to zero suddenly becoming a particle, an antiparticle, so maybe things can appear from nothing.

But for me, we don't need a moment of creation in mathematics. Because for me, there's no moment when there was no mathematics and there was mathematics. It's outside of time, we don't need to have a sort of temporal narrative about it. For me, mathematics just is. You're studying theology and one of the big questions is where did all of this come from? Do

Noah: I think there is something really powerful about thinking that we are part of this symphony like you talked about. Pythagoras is a crazy man in a cave in Samos who suddenly uncovered the key to something out there and saw himself in something. That's the mystical aspect of science which some people have argued has been lost, but I think it's still there to be found in in the nooks and corners. And I think it's really interesting, when we think about Pythagoras in this almost mystical mathematical experience, I wonder how well you think that could compute how well you think we could translate that into our modern language? Do you think that if we think back to Francis Bacon, seeing the universe as something to be conquered, quite violently discovered and its secrets opened up. Do you think changing how we think, seeing that we ourselves aren't the most important things in the world, that we ourselves aren't maybe even necessary for maths, and that we ourselves are subject to maths do you think recognising that we are just part of the numbers changes how we interact with the world around us?

Prof du Sautoy: Yeah, I think it does. I mean, I think, you know, our trajectory through

that. So that book was trying to push an explanation of what are those questions we will never be able to answer?

And then in a way that book started to drift into a little bit of theology. I liked Herbert McCabe, who I read during the course of that. He's a Marxist theologian in Oxford, he's died

With this in mind, in the next episode, I met with Dr. Gladys Kalema-Zikusoka, Uganda's first ever wildlife veterinarian, to discuss her conservation journey and her insights into the interconnectedness of animal and human welfare. I look forward to you joining me for that, and until then, thank you for listening. I've been Noah, and this has been