Welcome to *Entanglements*, the new podcast from the Jesus College Intellectual Forum. I'm so excited for you to join me, Noah, as we unpack and explore the human/nature relationship.

In the previous two episodes, we've discussed how nature has been seen through literature, first through the Romantic lens, and then the lens of American naturalism and the frontier ideology. One thing that I was left with after the conversations I had was the recognition that we simply cannot escape our subjectivity. I think that both Romanticism and naturalism, and crucially the apparent validity of both their experiences, show that our ideas of nature rely so much on pre-existing ideas of our place in the world and, therefore our perspective on nature is crucially, deeply intertwined with the way in which we see ourselves and our place within the world.

However, is an objective view of nature possible? To think about this I went to meet with Professor Marcus du Sautoy, Professor for the Public Understanding of Science at the University of Oxford.

I started by asking him how his mathematical background had prepared him for this role.

Prof Marcus du Sautoy: Being a mathematician is quite a good job for this because I think that mathematics is the language of science. And so in some ways, although Professor for the Public Understanding of Science sounds such a ridiculous title, you know, what is this guy going to know the whole of science? Of course I can't. But I think that actually mathematics does underpin many of the other sciences. And so I think it's quite a good base to actually try and do this role of being an ambassador for science.

Noah Rouse: You're an ambassador for science. What has that focused on and what is the area of your particular work?

Prof du Sautoy: Two answers here. One is my own research. I explore the mathematics of symmetry and numbers. Obviously symmetry is very important to the natural world and seems to be a very powerful explainer of things that we see around us.

But then on the other side is this role as kind of being a promoter for the importance of science. You know, science is having such a big impact on society because the technology that we're producing is just changing the world for good and potentially for bad. And so that's why in some sense we need the public involved in a dialogue about what science might do for us. And science I see as this massive superpower that's having a big impact on the world, and yet people don't really understand this place and the language that is being used. And so actually the scientific community have been very good at producing people to try create a dialogue between the public and what science is doing politically.

But you need to understand the science if you're going to be involved in a dialogue. So if you're talking about stem cell research, how can you have a debate if you don't know what a stem cell is? I sort of started getting involved in this around the turn of the millennium when there were a lot of scare stories about science. The people just didn't understand what

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 humans' interaction with the world around them. And strangely, this subject seems to be very powerful at being able to navigate the world around them. But then something slightly different happens where I think the human mind starts to enjoy exploring mathematical structures for their own sake, actually separate from the natural world. And I think you start to see that, you know, the real mathematics starts to emerge in those civilizations of Egypt and Babylon. These are civilizations which are really trying to change their environment, to build pyramids, and they need to know how many blocks of stone are in that pyramid, and so there's a real functional utilitarian reason that they're creating mathematics.

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 squared equals minus one, is there a solution to that? And that actually came out of questions of, well, what if x squared equals two? X squared equals two, 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 even the ancient Greeks are creating numbers which perhaps are only of the mind. Yet where did that square root of two come from? It came from trying to measure the diagonal across a square with unit sides. And that is coming from the physical world. That was a challenge people wanted to know when they were building things. Yeah, very often they would have a right angle to equal size. They wanted to know what the distance was across that.

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's and Leibniz's 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. That actually reflects very closely the mathematics that appears, which is the mathematics to understand a world in flux, or even the square root of minus one. We wanted that number for many years, but it took kind of the time of the French Revolution when people were like, hey, we can make up new names for the days of the week. We can make new measurements. And somehow that environment allowed us to say, well, but why don't we have new numbers as well?

But my feeling is that the basics of mathematics, for example, prime numbers, things I study, I don't think that's a construct of the human mind. I think that if I take 15 stones and 17 stones, 15 I can arrange in an array of three by five stones. The 17 stones I cannot arrange in that way. That's something somehow just essential to those numbers, that one can be broken down into products of two other numbers, the other cannot. And my feeling is that that's totally independent. You know, discovering that difference, yeah, we've been involved in that. You can see a moment in history when suddenly people realize, oh, that might be quite important. But I just think it was there waiting for us to discover.

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 we need an explanation of creation? And if you need an explanation of creation, you need a moment in time when things weren't and when they were, somehow. But for me, mathematics kind of avoids that, because for me, I don't think there was a moment where there was no mathematics. It's somehow outside of time and that's really important. If you're looking for a true reason for creation, you want something which is a temple outside of time.

So I think the reason that we're seeing so much mathematics just bubbling out underneath the world around us is because we are a physicalized piece of mathematics. Now how that happens and the explanation for that, I think mathematics can't provide an answer to that. That's what's interesting. I mean, we've gone on a long journey from your question, but my feeling is humans are a very irrelevant part of this. And some will argue the whole of mathematics is created by humans, you couldn't have mathematics without humans. I think it's the other way around. You can't have humans without mathematics because mathematics gives rise to the universe, which gives rise to the possibility of conscious beings.

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 science has been a gradual realisation of how irrelevant we are to the universe. The kind of Copernican understanding that we're not at the centre of our solar system, the solar system isn't in the centre of the galaxy. Oh my gosh, there are even more than just one galaxy! And I think that's interesting when it comes to the question of our consciousness, because that does seem to be something rather special that happened in our species, and we don't know whether it has happened in other species.

But again, I think there's still a rather anti-Copernican sense that we are at the top of this chain of consciousness. Maybe meditation might get you a little bit further, but we still have to actually have a challenge to…. And you know, maybe that's what artificial intelligence is starting to provide, is a little bit of a challenge of a different sort of mind emerging which is doing things differently to us. But I think there's another interesting point to this kind of Copernican viewpoint. When I wrote *What We Cannot Know*, there was a kind of feeling like, oh wow, science is so powerful. You know, I think we are still in a Pythagorean kind of mode where, wow, every week we seem to discover a new insight which gives us an understanding of not just the Earth around us, but you know, the Universe and potentially multiple universes and parallel universes and things like that. We're able to understand that the Universe is accelerating in its expansion even though we're stuck on our own planet. I mean, it's extraordinary what these tools are giving us.

But I do think there's something interesting because I think we still feel like humans, we should be able to answer every question about the Universe. And that, I think, is very anti-Copernican. It's sort of this conceit that the universe is set up as an exercise in the philosophy of science for us to understand, which is what I explored in *What We Cannot Know*. Whether there are questions that, doesn't matter how intelligent we are, just by their nature are unanswerable. Maybe because you're stuck inside the system and you can't get outside of that. If there is another parallel universe, how could we ever know that we're stuck inside our own? If it has no interaction with us, it might be consistent to hypothesize

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 now, and he has a lot on Christian liturgy and things. It didn't resonate at all. But there was one article which he wrote which kind of said, yeah, we've just made so many mistakes about this idea of the concept of God, it should never have been something that was given an embodiment, it was always meant to represent the unanswerable question.

And so that's why I think it's interesting, it's like going back to this idea of God of the gaps. So if there are things that we'll never be able to answer, then what sort of role do those questions have? Do they have any agency? Do they have any impact on life around us? If you can't answer them, then maybe they don't, so they're totally irrelevant.

It was kind of interesting to just understand, again, that idea of humans are, I think, are still in this wonderful Pythagorean glow of seeing the power of science to understand things. But I'm also interested in fundamental limitations of what we will never be able to know.

Noah: It's so interesting because that brings us back to participation. We're not observers, we're participating and we are limited by all the limitations.

The way you were talking there about finding the God of gaps or finding this strange encounter with human limits and the realisation that we're not worthy of being these entitled beings who think it's all about us, is a space where—the language of maths, the language of science, brings us into a space where it's not all about us, into a space where I can look at the tree and recognise it might be just about as much as the tree that it is me.

Prof du Sautoy: One of the things I find very exciting about mathematics and science in general is its universality. It has the power actually to stop it being about me and about actually a shared common language. That's what I find exciting going to conferences. I travel around the world, go to Russia or China. I don't speak Russian or Chinese yet somehow. We've got this shared language which is about trying to understand the universe around us and also this universe of the mind and mathematical universe.

So I think that actually as religion has fallen away as a powerful binder of society and provider of the stories which help us to understand the world, I do think that science, I think in the modern time is sort of filling that because people are getting a sense of wonder from understanding something bigger than themselves.

I think we've always enjoyed looking up at the night sky and wondering what's out there, but these tools are actually giving us some insight into our place, our rather irrelevant place in the universe. So I do think that science is providing us actually with a language of wonder, which is what we often want. We want to feel more than just our rather irrelevant individual place in the world.

And just being your part of that, that's interesting, your sense of participation and observation. You know, that is very exciting because, you know, we've only managed to do this by actively creating a lot of the experiments to up the energy, to be able to probe the very small, creating telescopes to see the very big and detect, for example, the first gravitational waves to confirm that, yeah, these are truly there. That's very exciting and all of these things require actually such team effort now as a big scientific experiment. But even down to actually, you know, the real questions about observer and participatory role when it comes to just very fundamental interaction of humans with the world around us because quantum physics says that everything should be living in a layered quantum state and it's only when we observe and interact with the world that actually it makes up its decisions about actually what it's going to do.

So there's an interesting idea of observer and participatory role that even occurs in something like quantum physics.

Noah: I think it brings to mind Stephen Hawking, who talks about not just looking up at the stars, but wanting to look at the flowers at your feet. It's almost this, I mean you're the expert on this, but maybe symmetry. And I think this is what has come up as a quite prominent theme in the interviews and research for this is while we're looking out there at nature, current nature, at the other, we're also without realising it reflecting on ourselves and who we are and who we are in relation to stuff.

You talk about maths as a sort of language of wonder, it's a very embodied language. I think it's really important to bust that myth, bust that bubble of seeing math, or science as this sort of cold, unemotive thing and recognising there is a human emotion connected to it.

Prof du Sautoy: Yeah, well that's very interesting, and I think even more so in relation to the mathematics, because I chose mathematics because there's actually even more freedom to be creative than maybe in the sciences. In the sciences you're kind of bound, trying to understand the world around us, and if a model doesn't fit, it's thrown away, it's not interesting if it's actually been proved to not be consistent with the data that we collect.

But in mathematics, actually, that doesn't invalidate, provided it's consistent. It may not model the real world around us, but it models some world that might actually still be interesting. And so I think that's where emotions come in, actually. Mathematics is weirdly more an emotional subject than science is, because science is bound by trying to explain the world around us, while I have the ability to create. And my decision about what I create and what I share with my fellow mathematicians is driven by emotions, because I don't want to just show them something which has no emotional resonance, it doesn't have a story to it. I want to show them a kind of world or a journey or a logical argument that surprises them, makes them go, well, gosh, but I didn't think that was connected to that. Just saying those two ideas are two sides of the same equation, that's amazing! So I think actually where there's true creativity, there's always going to be an emotional side to it because you're making choices about, I'm going to create this rather than this, and that's driven by my emotional relationship to it.

So I think in a weird way, mathematics is a more creative place because there's freedom to create multiple existences which are not physically embodied and therefore there are a lot of choices in that which are then driven by emotion.

Noah: I think that's the crux of what I'm trying to get across with this podcast, is we can be creative about the way we think about ourselves and the way we think about how we relate to trees I can see outside your window. Reading your symmetry books—first time I've been interested in maths and I think the first time (sorry, sorry A-level teacher!), but the first time I've been interested in reading about maths, I think it's that blend of personal story with maths. Do you think that your study has changed the way you connect with the world around you, with the tree I can see out the window or the stars in the sky?

Prof du Sautoy: I think it has changed because it's like a pair of glasses that I have because of this language that I'm able to see things in the natural world that others without that language are missing. So for example, being able to read the symmetry, being able to read the fractal structures, understanding that although this thing looks very complex, it could easily have had a very simple set of equations which gave rise to it. I often quote that passage of Galileo, which he said, you know, you cannot understand the world around us unless you understand its language, and that language is mathematics. It's a world of circles and triangles and other geometric figures, which means we cannot understand a single word. And you talked about us wandering around in a dark labyrinth without it.

And I do feel like the mathematical insights I've had over the years, the language that I've built up, has given me tools and has given humanity tools to be able to observe, but also then to change. I mean, that's what's so extraordinary. We can therefore understand how nature makes something, that fractal element, very simple idea, gives rise to complexity, we can apply that and then use that to create extraordinary technologies which are impacting the modern world.

And for me, we are physical entities of mathematics, and if mathematics is the language which runs this whole place, if you understand that language, it gives you an incredibly powerful way to be in the world.

Noah: I really enjoyed meeting and talking with Marcus and I found it fascinating to see how he highlighted the emotive aspect of mathematics, talking about it in an almost romantic way as a language of wonder. It reminded me that despite being small in the grand scheme of things, we do take an active role in the natural world. Even if we see ourselves as simply observers, we are deeply embedded within the world. And as Marcus pointed to, I think that recognising that we are embodied pieces of mathematics necessitates that we recognise to an extent that we are participants, however small, within the world and universe around us and of which we are a part.

I found Marcus' reflections powerful, that maths gives us the insight to observe, but also to self-reflect and, ultimately, to be in the world.

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 *Entanglements*.

Credits: Written, produced, presented and edited by me, Noah Rouse, on behalf of the Jesus College Intellectual Forum. Original music by Xanthe Evans.