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Welcome to IFLScience – The Big Questions, the podcast where we invite the experts to explore the biggest mysteries of science with your host, Dr Alfredo Carpineti.

I: Every second of every day, whether we're actively aware of it or not, we're using our imagination. We're sat in total daydreaming between other scenarios or other worlds, even just imagining what might be for dinner. It's said our imagination has no bounds, that we can picture anything we put our minds to. But how do we do this? On today's episode we're joined by cognitive scientist Professor Tyler Marghetis, who is here to answer the big question, how does imagination work? Hello, Professor Marghetis. Thank you very much for joining us today. We'll start by asking you to tell us a little bit about yourself and your work.

R: Yeah. My name is Tyler Marghetis. I'm an Assistant Professor of Cognitive Science at the University of California, Merced. University of California, Merced, it's the newest campus of the University of California system. We've only been around for around 15 years, so it's a brand new research university in the larger scope of things. It's a really exciting place to be. It feels like being at a start-up university at times. But originally I'm from Montreal, Canada. I went to college there and my life was devoted to competitive wrestling. I was on the Canadian National wrestling team for years and was the alternate for the Olympics in 2008 in Beijing. After that, I retired at the ripe old age of 23 or 24 and had to decide what to do with the rest of my life and decided to pursue my childhood dream of becoming a scientist. One thing led to another, I got into the PhD programme at the University of California San Diego. Studied there. Then had some additional training in the Midwest of the United States in a little town called Bloomington, Indiana. Most recently was a fellow at the Santa Fe Institute which is an interdisciplinary research institute that studies complex systems of all sorts, so economies, brains ecosystems, sort of a hotch-potch, a motley crew coming together to understand complexity in all its forms. From there I came to Merced California where I am now.

What I'm interested in is the limits of human imagination. All the things that humans do that allow us to think fantastic thoughts, maybe thoughts that have never been thoughts before, maybe thoughts that are only considered in some cultures and not others. My particular focus within that is trying to understand how people get stuck in ruts thinking the same thing over and over again, whether that's an individual person or an entire culture that considers the world in one particular way, and then how we transform, how we go from one perspective to another. How we have a rupture in our mind that leads us to consider a whole new conceptualisation or picture of the world.

I: That is absolutely fascinating. You're the perfect person to talk about the big question that we have in this episode, imagination. How does imagination work? How can our brain conjure stuff that we're not looking at?

R: Imagination ranges from the totally mundane to the absolutely fantastic. On the mundane end of things, imagination just means the ability to create mental imagery without sensory input, so it's our capacity to close our eyes and then picture in our mind's eye what the room in front of me looks like without actually getting real time information through my eyes, into the back of my brain that allows me to construct that image. It's the creative reconstruction of the outside world using only my brain and not input from the outside. That's something almost all humans do all day long. We're constantly maybe closing our eyes for a moment and picturing that fantastic meal we had the night before or thinking back to a really fun date we had years ago or imagining a trip that we went on and that's all imagination.

On the other end of things, you have the capacity to conjure up ideas or images that have just never been encountered before. I can say to you imagine a dogtopus, which is part dog and part octopus, and you can cobble together some vision of what that is even though that's probably something you've never seen before in real life or perhaps even in art or comics. That ability of our brains to cobble together different pieces, different concepts that have never been combined together, that's sort of the outer limits of imagination. That's when you get into the realm of creativity and invention, and imagination refers to that whole range from mundane imagery of a meal from the day before all the way to Picasso creating entirely new ways of representing the human form.

Now, in terms of how does the brain do that, well, it depends on what kind of imagination you're talking about. The mundane form of mental imagery, we're just closing our eyes and picturing the world as you were seeing it a moment before. That probably relies on the exact [unclear 00:06:25] used to perceive the world, so visual areas of the brain better towards the back of the brain in the occipital lobe. A funny thing happens, though, where some people actually aren't able to do that at all. Maybe around 1 in 50 of the human population has what's known as aphantasia. These are people with no capacity for mental imagery. This is something that we've known about for maybe 150 years, but it's only in the last few years that scientists remembered that this had first been described by Galton back in the 1880s. There's been a flurry of research trying to understand what's happening, what's different in the brains of these people with aphantasia. It looks like some of the story has to do with a reduced connection between the parts of the brain that we use for executive control, for bossing around the rest of our brain, so those are parts of the brain that are in the front or sort of top/back, so frontal and parietal areas. It seems like in folks with aphantasia those areas maybe are less able to interact with those visual perceptual areas to basically tell them what to do when they're not getting direct input from the outside world through our eyes.

That's how mental imagery works. We're basically recycling the parts of our brain that have evolved to literally perceive the world and we're using them in this more creative way to imagine what the world would look like if we were looking at it without any input from the outside world. On the other end of things, we're trying to understand how imagination works in the mind of Picasso or Richard Feynman, a great physicist, or these folks who have

transformed our understanding of the arts or the sciences or mathematics, there the story is going to be more complicated. I think it's going to be a story that forces us to go beyond the brain, so it's going to be the brain in collaboration with our bodies and the world. Here's what I mean by that, a classic example of imaginative creativity is the scientist Archimedes of antiquity sitting down into his bath, having an insight, screaming, "eureka!" And so the story goes, running through the town naked screaming, "eureka! eureka!" That he'd had this imaginative insight, this creative breakthrough.

Now, a lot of people often think of that as an example of pure creative imagination where at a moment of rest the idea popped into his brain and he had the insight. But the interesting thing was that the insight he had was actually about the displacement of objects and water. It was about density. Where did he have that insight? When he himself was putting his body into the bath. We see there's this connection between his interactions with the world, the kinds of science, the kinds of connections that the world offered him and the actual creative breakthrough that occurred in his brain. That seems to be a recurring theme across imagination of this creative sort, whether we're looking at the arts or the sciences or dance or even mundane creativity that we have in our daily lives.

The mortals like me and you, Alfredo, who aren't Archimedes, when we make those creative connections, it's often our brain playing some role of putting things together, but then also the world offering these tense, the clues, these cues, these connections that we then take advantage of.

I: Wonderful. Thank you very much for that in-depth answer. I think that leads well on to the next question. I was going to ask about the eureka moment, but clearly it's balancing between external stimuli and our creative thinking. But is there an understanding on how the spark of genius comes into play with our imagination?

R: Yeah. These moments, these eureka moments or these sparks of genius, I think are some of the most fascinating moments because they really get at this tension in the human mind between our ability to really hold fast our beliefs. We're a stubborn species and you see that in political debates, religious wars. When people have a way of thinking about the world, they really stick to it. But on the other hand, we have this capacity for radical reconfiguration, these breakthroughs, these eureka moments, where seemingly in a flash we go from one way of thinking to another one entirely. We know a little bit about how this works. One component is that there seems to be this trade-off between the benefits of exploration and exploitation. Now, by exploration, I mean considering a broad range of possibilities and exploitation I mean really drilling down into one good idea that you've settled upon and discovered. Scientists use these words to apply to how non-human animals forage for food in the world. A squirrel could explore a wide range of areas of really exploit one particular area where there's a lot of really fantastic nuts. It seems like the human mind does something similar, so we're able to explore a wide range of connections and then also exploit one set of connections or one particular concept or one area of our space of ideas to try to get as much out of that area or idea as possible.

What scientists have found is that if you look at the careers of scientists, artists and even film directors, you see that they'll often start with a period of exploration where they're pursuing lots of different genres or ideas or styles or maybe collaborators and then when they hit on the idea that really made them famous or made them rich or had a huge impact on the history of science so they're a hot streak, as they call it, then they switch into that other mode, that exploitation mode where they focus in on that one particular idea that through that process of exploration they discovered, aha, there's something really promising here and they're going to double-down on that. That happens on a timescale of years and decades in the cases of the careers of scientists or artists or film directors, but it also happens moment to moment when we're stuck on a puzzle.

One of my fantastic students, [unclear 00:14:02], she's been looking at how mathematicians have these eureka moments or these breakthroughs or these strokes of genius. What she's finding is that as they're about to have that flash of insight, that aha moment, they start to explore more surprising connections. Connections between ideas or connections between graphs or writings or equations that they've drawn on a blackboard that they hadn't looked at before. That's this exploration mode where you're pursuing connections that maybe you didn't think of pursuing before. Maybe you didn't think they were worthwhile, maybe they seemed too unusual to work, but in the lead up to that eureka moment, all of a sudden those seem to be on the table and that's a departure from what was happening before. A key part of that flash of insight is openness to pursuing new connections so that you can find that one connection that is really going to make all the difference.

The other thing that I wanted to say was that another key component for creativity, and this is I think part of why creativity seems so mysterious and why these imaginative moments of breakthrough seem so magical, as I said, is that they're often involving an accident. Accidents are such a crucial part of the history, of science and art and dance and literature. I gave a bit of an example earlier when I mentioned Archimedes where really it's sort of an accident that as he sat into the bath he noticed his body was displacing the water upwards and that accidental noticing prompted him to have this realisation about density and the displacement of water. That happens all the time.

When Alexander Fleming discovered penicillin, one of the first great antibiotics, what happened was that he was a kind of a messy, untidy scientist. He'd gone away for the weekend and had a little break. Then when he came back to the lab, he noticed that one of his petri dishes has been contaminated with a fungus. Normally, you don't want contamination in your petri dishes if you're a biologist working on microscopic life. But in this case, that fungus happened to be of penicillin variety which people did not realise at the time is a fantastic antibiotic. What he saw when he looked inside the petri dish is that all around that fungal invasion there was this dying off of the bacteria, the harmful bacteria that he had been growing in there. That was that breakthrough that led to the consideration of an entirely new way to treat infection that we still rely on today, so penicillin is still widely used to treat infection. That was a total accident.

Often times this process of exploration isn't an intention purposeful self-driven exploration, it's the kind of exploration that's only possible when the world forces us [unclear 00:17:42] when the world presents us with things that maybe we wouldn't have wanted there in the first place,

and that partnership, that dance between what we think we want and what the world offers up is often where the magic or imagination happens.

I: We already mentioned people with aphantasia, and you already mentioned also how different societies have different abilities to imagine and things they can imagine, etc. I would like to know if imagination works pretty much the same for everyone or how different it is, and how much is it shaped by our physiology and how much is it shaped by our culture?

R: Yes. This question of whether imagination is more nature or nurture gets at this classic question in the sciences of human nature and cognition and the mind, which is, is it our genes or our experiences that shape the kinds of thoughts that we have? Imagination is no different from the rest of the human mind in that the answer is almost always both. Absolutely, we have brains that operate in certain ways, that give in standard reliably reoccurring features of the environment that we grew up in. Our brains develop in often very similar ways. But there's also this influence of the kinds of experiences we have, including experiences that are entirely cultural. One really good illustration of this, I think, is in how we imagine the nature of space and time. The two foundations of our understanding of the world and for a long time scientists assumed that no matter what society you would go to, people would at least agree on how to make sense of space and time. They might disagree about the right way to structure your government. They might disagree about religious beliefs, but at least when it comes to the space and time, there we can have a foundation of mutual agreement.

What scientists have discovered more recently is that even with space and time, there's this radical variety of perspectives, of ways of imagining the nature of space and time across cultures. I'll give you an example. In the US and in the UK and in Canada and just about anywhere where people speak English primarily, the standard way to think and talk about small scale space is in terms of ourselves. We'll say, oh, something's to the left or something's to the right. It would be really unusual if I were at a dinner party and I said, oh, could you pass me the fork that's to your north/north-east. That would be kind of an unusual thing to say. Much more natural to be, oh, to your left. And for a long time, going back to philosophers like Immanuel Kant, the assumption was that that was the starting point for understanding of space, the way that people are going to imagine space is going to be relative to ourselves, to our bodies.

Then more recently people discovered that that's not true, there are cultures that speak languages that don't even have words for left and right at all. The Guugu Yimithirr, an Australian Aboriginal group, don't have words for left and right and primarily refer to the world in terms of North, South, East, West, towards the mountains, away from the mountains, these kinds of non-egocentric ways of orienting themselves. I study a group down in Oaxaca, Mexico, Mazatec speakers, and they're a part of the Zapotec indigenous family and their language has words for left and right hand but doesn't have words for left and right space. They can use those words to refer to their hands, but not for spatial relations outside in the world. But they also speak Spanish, which like English uses left and right primarily to refer to the world. Here you have a group that has two different ways of imagining the nature of space [unclear 00:22:41] to their language.

An interesting research question is, okay, what happens when people have these different fundamental ways of imagining the structure of space? In some of our work that we've done out there we've looked at whether people change the way they're imagining space when they switch from one language to another. It looks like the answer is no. It looks like there what really matters is do you understand the meaning of the words left and right. You could master the entire language. You could be part of one culture or the other, but the second you learn those words, it seems to open up a new way of thinking about space where you begin to rely more and more on that egocentric body-based, self-based way of understanding the nature of space.

There's an example where this fundamental part of our imagination, of the way that we structure our understanding of our world that is the way we think about space depends fundamentally on the kinds of bodies we have, the kinds of brains we have, but also the kind of experiences and influences we get from our culture and from our language. That's true for the way that we think about space, that's true for the way we think about time, that's true for the way we think about numbers. All of these foundational building blocks for human imagination exhibit this kind of cross-cultural variety that reflects differences in experiences around the world.

I: Thank you very much. While you were talking there, a thing that I kept thinking is also colours. In my experience, it's the fact that English language hasn't got a specific colour for sky. They say sky blue, but it's very vague. While in Italian we have Celeste which is the colour of clear blue sky. It's both cultural and inside us. We're very grateful for Tyler taking the time to talk to us today and for helping us better understand the depths of our own imagination and exploring the mysteries of our minds.

Thanks for listening to IFLScience – The Big Questions. Head over to iflscience.com and don't forget to sign up to our newsletter so that you don't miss out on the biggest stories each week. Until next time.

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