STORIES OF IMPACT SEASON 2

S2E3: Transcript
The Honeybee Brain
with Dr. Andrew Barron and Dr. James Marshall

Tavia Gilbert: Welcome to Stories of Impact. I'm producer Tavia Gilbert, and in every episode of this podcast, journalist Richard Sergay and I bring you a conversation about the newest scientific research on human flourishing, and how those discoveries can be translated into practical tools.

BIRD SONG, BEE BUZZ

We learn from an early age, or maybe it's such an ancient knowledge that it's hard-wired into our subconscious, that one of the most essential species on earth — the species fundamental to the pollination that enables plants to seed, reproduce, and create the fruits that humans rely upon for our own survival — is the honeybee. And we recognize the buzz of the honeybee, perhaps also instinctually recognizing that its sound exemplifies bee characteristics: reliability, cooperation, stability, and sustainability.

DRONE BUZZ

Can you identify *this* bee-like buzz? It sounds like it could almost be a swarm of bees, doesn't it? That persistent, mechanical hum is not exactly a relative of the bee, but it is related to the bee species. That droning sound...was a single drone, a flying robot that, although still a pretty new technology to many, is already and increasingly becoming commonplace in our modern, networked society.

There's not just a close relationship between the sounds of bees and drones, but a deep relationship between the development of robotics and artificial intelligence, and the brain of a honeybee. What we'll learn from today's conversation is that by understanding the honeybee brain, we might not only someday soon develop robotics and AI that are as skilled and intuitive as bees, but robotics and AI that reflect the bees' positive virtues.

In every episode of this season of the Stories of Impact podcast, we're asking the questions: What are diverse intelligences, what do we learn by studying them, and how can those revelations support human virtue? Today we're going to spend time with Drs. Andrew Barron and James Marshall. Richard Sergay sat down with these two scientists to find out how their unique areas of expertise came together to apply discoveries about the intelligence of honeybees to the development of smarter, more capable artificially intelligent robots — machines like drones that might increasingly assist humans in solving some of the most complex problems we face as a species.

Andrew Barron: So my project is completely awesome, I love it. My project is particularly focusing on honeybee intelligence because it gives us such an informative comparative lens on the intelligence of other animals including humans.

Tavia Gilbert: That was Dr. Andrew Barron, Associate Professor of Cognitive Neuroethology at Macquarie University in Sydney, who brings his passion — the honeybee — to his collaboration with Dr. James Marshall, Professor of Theoretical Computation and Biology at the University of Sheffield. Dr. Marshall explains why honeybees are the perfect species to study in order to apply their unique intelligence to artificial intelligence.

James Marshall: 11 What attracted us initially is its simplicity. The whole point of the bee brain, it's only a million neurons but it has this huge behavioral repertoire.

Tavia Gilbert: The brain of a human is estimated to have 85 billion neurons, so a bee's brain is infinitesimally small in comparison. Despite that minute size, bees have an extraordinary kind of navigational and discerning intelligence, and those are characteristics the research team wants to better understand and apply to AI.

Andrew Barron: 27 So in a bee brain, I have one million neurons to work with in my system. We're trying to create a computational model of this bee brain.

James Marshall: 17 So it's like reverse engineering a computer or something like that. You have something that works. It's a kind of biological robot if you like and if you can tease it apart, figure out what generates its behavior and how then that's the process of reverse engineering. So it's what we've done with computers and other devices really since IBM and the PC was invented. Competitors tried to reverse engineer the IBM and come up with their own versions. So I thought if we could just reverse engineer the bee brain we could actually try and really advance the state of the art.

Andrew Barron: We have these tiny little animals with really minute brains, but you only have to spend a bit of time in the presence of a bee to understand that you're in the presence of a very cognitive agent that is actively deciding and choosing moment by moment how to organize what is a, intellectually very demanding lifestyle of having to gather pollen and nectar from all these dispersed flowers and not run out of fuel and make a profit and get it back home.

Tavia Gilbert: The complicated organization and decision-making that the seemingly-simple-brained bee performs with innate brilliance are exactly the kinds of tasks that scientists hope artificial intelligence will one day perform with as much skill and ability.

James Marshall: I realized that, you know, with only a million neurons in the bee brain they were already well in advance of our own abilities in artificial intelligence and robotics.

Andrew Barron: So it gives us a fantastic way to look at fundamental questions of how brains function. It's also a bridge. So if we can model the bee brain, we can take insights from those models and translate them directly into technological applications. If we can model the bee brain, all of this intelligence, all this dynamic, autonomous behavior that we get out of bees, we should be able to capture that in the model. There'll be things that we can learn from that that we could translate into robotics.

Tavia Gilbert: The bee brain gives insight into advancing robotic technology, which will allow scientists to solve the persistent problems with existing tech.

Andrew Barron: Bees have evolved for millions of years to be fantastic autonomous behavioral control systems. They solve very, very complex image processing systems. They're amazing navigators across very large distances. They're really robust, they're really reliable. All of these are current challenges in autonomous robotics.

James Marshall: They can navigate long distances which is a feature we're particularly interested in. They can learn a route through a complex three-dimensional environment and then subsequently be able to find their way back to where they came from and then recapitulate, follow again that same root to get back to the particular point of interest, and our own machine learning and AI algorithms for navigation just aren't that sophisticated or reliable.

Tavia Gilbert: And so far, is the research proving itself to be of value?

James Marshall: We've made big advances recently in working out bees how we see the world, navigate through the world, avoid collisions. So I think it's definitely taught us lessons already looking at the bee brain that are directly applicable to how we control robots, you know, navigating in difficult environments without crashing into things.

Tavia Gilbert: Current technology isn’t just challenged by the problem that robots’ might...crash into things. There’s another problem with today’s robotics and AI development that honeybees could help scientists solve:

Andrew Barron: One of the biggest challenges in AI is image processing and particularly image processing at real time in complex environments. There's been a lot of advances in that, part of which is better sensory systems, part of which is better compute power, faster compute power, part of which is learning shortcuts in how we need to process the world and what matters.

What interests me is that the amount of compute power that a bee puts into processing images, images of its world, is far, far, far, less than the amount of compute power that we're currently using in image processing programs. And yet bees show probably even greater robustness because they're solving a three dimensional flying challenge across enormous distances. So I think that there were still tricks that we could learn from something like a honeybee that could streamline this real, robust challenge of image processing.

Tavia Gilbert: Bees' ability to process enormous amounts of visual information and navigate through a vast environment is extraordinary.

Andrew Barron: Honeybees have been documented to find their way home from 12 kilometers away. In a routine foraging flight, bees will fly five or six kilometers which doesn't sound much but when you scale that by the size of an individual bee, that's a really huge distance. The bee moment-by-moment's making very, very complex evaluations about how it's going to invest its time for the maximal benefit of its colony. Is it going to forage today? Is the weather good enough for it to forage? If it's going to forage, what flowers is it going to go to? Is it going to get minute droplets of nectar, all hidden in these individual flowers? Or is it time to give up and take what it's got back to the hive? All happening on board within this tiny brain with no director; fully autonomous control of an extremely complex, information-based problem. Bees have cracked that. The success of bees in their environment has proved over millions of years how well they do this. And I think learning these tricks is what's going to help us with robotic applications.

Tavia Gilbert: Dr. Marshall's research supports that theory.

James Marshall: That's right. So, we, well, we're finding that actually bee navigation may be a lot more map-like than people have previously assumed. We basically take a kind of modular approach to the bee brain, the bee brain is a very modular computational device. And so we will look at the brain regions associated with early visual processing for example, and try and model those. But then we can go deeper into the brain and model things like what's known as the visual compass. So how the bee represents its orientation and its position with respect to its environment.

Tavia Gilbert: In working to model that computational device of the bee brain, Dr. Barron has only deepened his respect for the complexity of honeybees, relative to their brain size.

Andrew Barron: The honeybee brain is very small, but it would be wrong to characterize it as a simple system. We do still have one million neurons in a bee brain, and they are organized in quite beautiful structural regions that interact and intersect in very complex ways. The benefit of this system is that on that scale, it's comprehensible. It is something that we can model and we know enough about how it's connected that we can make those models biologically realistic.

But I am not imagining this is a simple task, these are simple models. And the complexity of the system is actually why we need to model it. Because often the way that we think it will perform is counterintuitive when we actually examine the how the model actually performs.

Tavia Gilbert: And Dr. Barron makes one more point about the unique modeling potential of the honeybee brain:

Andrew Barron: Regions that we talk of a lot in the mammalian brain like the cortex, just not there in the insect brain. And there's not even anything like it. So it's a fundamentally different information processing system. And for me that point of difference is one of the strengths of working with a honeybee. We learn a lot about fundamental principles when we study different systems and the bee is different enough that it's really insightful.

James Marshall: So really what we'd like to do is make silicon versions of bee brains or at least if the aspects of the bee brains that generate behavior we find useful for our own robots, so especially around navigation. So we're building drones that can fly in a comparable way to a bee but not exactly the same as a bee. And really we'd like to just try and distill the essence of how the bee does what it does and put that in computer routines that we can use for our robot control. In particular we want to be able to reproduce, for example, the collision avoidance or navigation abilities of a bee in robot form.

Andrew Barron: The bee is doing it with incredible computational efficiency. So if we can solve how the bee is doing it, there will be insights there that we can learn that we could translate across to make robotics more efficient, more robust, also more comprehensible. Systems that, if we start with a deep understanding of a system like an insect brain, we have an understood system that we can apply in robotics.

Tavia Gilbert: Does Dr. Barron believe that the bee brain is the answer to all robotics questions?

Andrew Barron: It would be naïve to say that we will solve all robotic problems by understanding the bee brain. Of course we won't just carbon copy one system into another. We need to look intelligently about what we want and need from robots that we'll be comfortable sharing our world with, and then we take the most useful insights from things like a honeybee that can help us get to where we want to be.

Tavia Gilbert: And where does this team imagine it is that we want to be? What kind of artificially intelligent robots do the researchers imagine we want to share our world with? Dr. Marshall sees applications for drones and AI-equipped robots to work in service of human beings, especially during times of catastrophe or crisis.

James Marshall: So the advantages would be saving with labor, for example. So at the moment it can take for remote operation of a drone it can actually take more than one human pilot. So if you imagine for example trying to deploy drones to search for survivors of an earthquake or something like that, time is going to be of the essence, you want to automate as much of the process as possible so that you can be searching in parallel. Our vision is if we could have fully autonomous flight and navigation for robots then we could have some real benefits from that kind of technology.

Tavia Gilbert: Dr. Barron also sees potential applications for drone technology that would benefit not only people, but our environment.

Andrew Barron: If we're thinking about let's imagine autonomous drones that we could use in exploration or agriculture or in mining, or even in recycling from landfill, collecting scattered sparse resources where you can't predict where they are, they're valuable but they occur patchily and unpredictably. And you've got to optimize finding those looking after yourself and getting them back to one point and making a profit. That would be the holy grail for so much robotics. Bees have solved that with this minute brain.

Tavia Gilbert: Our expectation is that we will learn from bees so that we can build better robots that will learn, make decisions, evaluate different possible answers and choose the one that is the best for us. But aren't bees born fully equipped with all the knowledge they need to navigate so skillfully and process visual information so completely? Aren't swarms of bees behaving without conscious awareness, drawn by instinct from hive to nectar and back again? Are they actually *learning*?

Andrew Barron: The honeybees really are spectacular learners. They learn very fast and very robustly. As an example, if we give a honeybee something simple to learn this odor is where you find nectar, it will learn that on one trial. If you give it three trials, it will learn that for the rest of its lifetime. So that's very fast acquisition of relationships between information. So there's a whole list of cognitive facilities that we thought set humans and mammals apart from simple animals. Then we look at the simple animals, and we find that's not true. Honeybees can actually adjust their behavior in response to their state of knowledge about a choice. They can even learn things that we would consider to be abstract concepts. That hasn't been shown in any other invertebrate that I know of.

Tavia Gilbert: And if invertebrates such as the honeybee can be such fantastic acquirers and processors of information, then Dr. James Marshall, can apply what discoveries he makes about how the bee brains work to the most cutting-edge artificially intelligent robotics — machines designed by humans to quickly process information...or *learn*.

James Marshall: So bees are often underappreciated in terms of how intelligent they are individually. Individually bees can do complex learning as well as the simple kind of learning that you see demonstrated in conditioning like Pavlov's dogs is a famous example.

Andrew Barron: Many things are impressive about the honeybee — complex learning, complex memory, complex navigation, complex assessment, concepts and, and complex spatial calculations and complex assessments of relationships — How can an animal with just 1 million neurons do that?

James Marshall: That seems like a much higher level kind of cognitive ability than people have typically assumed bees and other insects are able to employ.

Andrew Barron: There's an awful lot more that this insect brain can do than we realized. I'm ranting, I always rant when I talk about bees but that's because how they do this — how they achieve this is what really fascinates me. What really motivates me in this work, it's not creating the list of what the bees can do. It's using the simplicity of the bee brain to ask the more insightful question of how is the bee doing this?

Tavia Gilbert: Dr. Barron is clearly passionate about bees, but isn't there another animal he could have devoted himself to? Why wouldn't lab rats be just as good as bees, or even better?

Andrew Barron: In many tests, even these tests of very simple learning or even tests of very complex learning, we see the bees learning faster than rats. I don't have an answer for you as to why that is yet. It fascinates me. It's, we have an organism where our assumption is, this is smarter. And yet in a whole battery of tests of learning, tests of memory, tests of spatial cognition, the bees are outperforming the rats. It may be that the simplicity of the bee brain is actually helping them learn these elemental relationships.

Tavia Gilbert: Another reason bees are more suited to equip technologists with more tools for robotics? Bees communicate information with each other — a means of movement-based communication that is key to the bee's individual and collective identity and purpose.

Andrew Barron: The honeybees have this symbolic dance communication. Now that is often described as a dance language. So we don't have language in the sense that we have human language anything like a bee, but that's not to underestimate the sophistication and the elegance of dance communication as an information communication system.

Tavia Gilbert: And what Dr. Barron understands about how bees share information might inform how artificial intelligences can someday teach each other.

Andrew Barron: Communication in honeybees is very, very rich. The dance language is compelling, and there's nothing else quite like it. And what sets the dance language apart is that they are transforming information about distance and direction to things in the real world, to these remote food sources, into a single vector that they can then signal through a dance. And what is astonishing is that other bees can backwards interpret that dance and translate a movement in the dance to a flight vector in space. No other bee does that, that really does stand out to me as a remarkable example of an evolved behavioral innovation.

Tavia Gilbert: When our interviewer Richard Sergay accompanied Dr. Barron out into the field, to get up close and personal with the bees, Dr. Barron reinforced the two aspects of his admiration for bees: as good, cooperative community members, and as individuals. Here’s Dr. Barron in a bucolic field in Sheffield, where he shows off his hives and their colony occupants.

Andrew Barron: There's a reason that social insects dominate every terrestrial ecosystem. When you get 50 thousand of them cooperating for one purpose, which is to maintain their colony, it's amazing what they do. When you open a hive like I've just done, you see their collective behavior, you see the structures they've built, you see the organization of that society. You can't do anything but admire it, you can't. They are the most beautiful, phenomenal creatures, they really are. Each of these bees is smart and dynamic and wonderful in its own rite.

Tavia Gilbert: Surely Dr. Barron doesn’t have an attachment to bees that extends to affection, does he? How can someone get emotionally attached to an insect? In fact, what is he seeing that reveals their individuality?

Andrew Barron: When you work this closely with one individual bee like this, you see their intelligence, you see their individuality. I've discovered to pay attention to them, and to give them the attention that they deserve. And because they're small and because they don't look like us and because they have these hard, expressionless faces, we don't emote to them the same way we do to other animals. We don't give them, innately, that attention.

Tavia Gilbert: Back indoors in the lab, he continues to explain why he feels a greater affinity with bees than he does the most popular domesticated animals.

Andrew Barron: We all have an attachment to cats and dogs because they're so naturally empathic. We've, we've bred them to have faces that more closely resemble us and to give expressions that more closely resemble us. We've bred into them this empathic response that we then emote onto them. When you just look at the bee's face it gives nothing away. It gives you nothing. Its face is a blank mask. We don't know whether we're looking at an intelligent entity or whether we're looking at a miniature robot. Sometimes our assumptions about what is intelligent are misled.

And so the appreciation of the bees' intelligence is very clean and very pure. I have as warm a relationship with bees because I've developed so much respect for them. When I work with bees, usually I'm working with just one individual bee who I've paint marked or number marked so I know who she is. And I'll follow her really closely over a whole day when I'm training her to do something quite complex. In the course of that day you get this really privileged insight into the kind of intelligence that this animal has and you realize just how astonishing it is, and just what a cognitive and elegant and beautiful entity this animal is. I mean what do you want, wagging tail or dance?

Tavia Gilbert: If you go to storiesofimpact.org, you can find a link to the video version of this episode, meet Dr. Barron and Dr. Marshall, and see for yourself the beauty and the elegance of the honeybee.

But isn't there a darker side to the research Dr. Barron and Dr. Marshall are teaming up to study? In fact, here's a more pointed question, as, like me, one of the first things that may have come to mind when you heard about the improvement on drone technology is its potential use in warfare. Are Dr. Barron and Dr. Marshall collaborating to advance technological developments so that we can become better in battle? After all, that's often how machines such as drones and robots are cast in our media and popular culture — as terrifying, near invincible warriors. Is that what these researchers are contributing to?

Andrew Barron: It's inevitable that the military would be looking at something like this. That's not something that interests me. What interests me is the capacity for safe robotics. Whether we like it or not, we're in this robotic revolution. It's happening. It will only accelerate even further. What we want from robotics, we want devices that are useful and that help us. But we need them to be trustworthy, and we need them to be safe.

Tavia Gilbert: Until Dr. Barron planted the seed of this idea, I admit that human virtues like safety and trustworthiness hadn't been a part of my thinking about technology that seems to me like it could be, in fact, antithetical to humanity. Like Dr. Barron, Dr. Marshall is not ambivalent about the potential use of his work.

James Marshall: We need to get away from the view of scientists just doing science and not considering the possible societal consequences and early on think about what could the applications of this be, what could the consequences of this be for society and then how can we mitigate that?

Tavia Gilbert: Does Dr. Marshall worry about potentially threatening societal consequences?

James Marshall: Well I think the obvious potential problem for autonomous systems research like we're doing is, what is the nature of the autonomous systems you're developing? And this is a problem that isn't peculiar actually to bioengineering or you know machine learning or AI. It even goes back to the wheel. I mean, wheels can be used for getting people around to do nice stuff or getting people around to invade countries or something equally undesirable. So you really just have to think about, how can you encourage the positive uptake of the idea and really mitigate against the negative consequences.

So, yeah, I worry about it. I think it's part of my job to worry about it. And to really make sure that the positive societal benefits outweigh the negative ones. And I think on balance they will do. And it's our job to ensure that.

Tavia Gilbert: Dr. Barron is also doubly motivated — by a desire to use his research on bees to build the most effective machines that have built-in boundaries around the applications for AI.

Andrew Barron: The existential threat around AI is that we create a thinking entity that rapidly starts to outthink us and that realizes that its interests don't align with ours. And there's a lot of I think justified concern about that existential threat.

Tavia Gilbert: We've consumed stories for decades, at least, that show that, even with the best of intentions, scientists might unleash on society machines that grow completely out of control — their capabilities and power exceeding man's ability to manage them. Is Dr. Barron naive in thinking that artificial intelligence can really be appropriately managed and only programmed to serve, and never undermine, human health and safety?

Andrew Barron: So this is really where my interest in the translation comes from. If we really deeply understand a system, and really comprehend it, we could create a system where its capacities are known and its limits are set and setting the limits will help obviate that existential risk.

Tavia Gilbert: It's clear from both Dr. Barron and Dr. Marshall that we're only just beginning to understand how much honeybees have much to teach us about intelligences that may help protect and safeguard our communities in the future, and that safe, trustworthy, and boundaried machines will be a part of our future. But there's another valuable offering that bees have to make: not only can they give us insight into how to develop AI that will be good for us, they can help us better understand our own species.

Andrew Barron: The similarities between the neurons in a bee and a human massively outweigh the differences. The honeybee is closer genomically to a human than it is to a fruit fly. Which sounds weird, but that's just the way evolution works sometimes. And it's going to give us what we urgently need, which is a lens into how our intelligence works and how our brain works.

Tavia Gilbert: Back out in the field, Dr. Barron expands on the link between the honeybee brain and the human brain:

Andrew Barron: The honeybee brain will help us understand the human brain by contrast. Our brain is massive, we have an enormous repertoire of skills. The honeybee's brain is tiny. But it solves most of the challenges that we solve. It has to gather food, return to the hive, maintain its society. Understanding how the honeybee is able to achieve all of that with so little, is going to help us correctly frame the question about why our brain needs to be so big, and what capacities we have from that, that the honeybee doesn't have.

Tavia Gilbert: Do we have time enough, though, to study honeybees? While I've been thinking about Dr. Barron's research today and listening to this interview, I've gotten two more emails in my inbox imploring me to make a financial contribution or call my elected representatives in order to help save the bees. If they're this important, this crucial to understanding ourselves and understanding and making best use of new technologies, are we working against a ticking clock?

Andrew Barron: We're now at a point where in the industrialized world, honeybees are not doing quite so well. In moving bees around the world, we've moved every bee disease everywhere in the world as well. So their disease threats have gone up. We've spread pesticides over large amounts of the world, which, of course, they're insecticides designed to kill insects, bees are insects, insecticides kill bees. That's a no-brainer. We've also removed natural vegetation and replaced it with crop monocultures. Everything flowers in one go, it's only one type of nectar, one type of pollen, it all stops flowering in one go, and it's then an effective desert for a honeybee. For these reasons bees are not doing so great. Climate change is also hitting them quite hard. We need to be worried about this.

If we lose bees, then our crop plants will go unpollinated. It's-- it's crazy to me, it's-- we talk about the problems and the threats that are facing all bees, not just the honeybees, and as I said, the risk to bees actually is far greater and far more immediate for the bees that we're not looking at. The honeybee we look at, we give our attention to it. The honeybee is actually doing ok because we've put already so much into maintaining its populations. It's the bees we're not looking at that we should worry about the most. But what frustrates me is that this is not an unsolvable problem. The problems come about because of the way that we manage the environment.There are solutions that are far more sustainable, far more sustainable agricultural solutions that would then tip the balance and make the environment better for bees. And then the bees would do better. It's not unsolvable, it becomes an economic problem to solve it, it's not a scientific research problem to solve this. We know what needs to be done, we simply need to implement it.

Tavia Gilbert: The research of Dr. Andrew Barron and Dr. James Marshall gives us insight into the different directions available to us as a human species of learners and innovators. We can choose to study AI and robotics and the diverse intelligences that will enable us to make them more capable, applying that knowledge to serve humanity, or to become more ready for warfare. We can choose to honor species that are seemingly not like us, recognizing not only their intelligence, but what they have to teach us about how they have successfully survived for millions of years. We can be awed by the interconnectedness of human beings and our genomic relatives, the honeybees, and do everything we can to preserve their habitats and health, or we can sacrifice their safety at our own peril. As we continue to develop advanced technologies, my hope is that we'll choose the sustainable path, for the honeybees' sake, and our own.

We're excited for our next story in the Diverse Intelligences season. We'll return next week with a conversation with Brian Hare, who studies the diverse intelligences of animals and has found a surprisingly virtuous force of natural selection across a variety of species:

Brian Hare: Many of the differences we see between wolves and dogs, we see between bonobos and chimpanzees. Why is it that you have these two distantly related pair of species that have become so similar in the way that they've changed from one another? What was the process that drove it? We think the same evolutionary force has shaped dogs from wolves and shaped bonobos from a chimpanzee-like ancestor. And we think that force is selection for friendliness.

Tavia Gilbert: We look forward to bringing you more from that conversation next week. In the meantime, we hope you enjoyed today's Story of Impact, and that you're looking forward to hearing more about honeybees, dogs, AI, and more. If you liked this episode, we'd be grateful if you would take a moment to subscribe, rate and review us on Apple podcasts. Your support helps us reach new audiences. And remember, for more stories and videos, please visit storiesofimpact.org.

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