

PLOS Science Wednesday: Hi Reddit, my name is Lars and I published a PLOS Biology study showing bumblebees can solve a string-pulling puzzle, and share the innovation with their other bees in their colony – Ask Me Anything!

PLOSScienceWednesday¹ and r/Science AMAs¹

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Abstract

Hi Reddit, My name is Lars Chittka and I am a professor of sensory and behavioural ecology at Queen Mary University of London. My research focuses on the learning processes, the sensory organs and the social behaviour of bees, and their interactions with flowers. I recently published a study titled “Associative Mechanisms Allow for Social Learning and Cultural Transmission of String Pulling in an Insect” in PLOS Biology. In this study, we discovered that bumblebees can solve a string-pulling puzzle, where they had to pull on a thread to retrieve a reward from an artificial flowers that was presented under a glass table, so that bees could see it but not reach without pulling the thread. Moreover, we found that inexperienced bees could learn the technique from experienced ones, so that the skill spread rapidly to a majority of colony members, in a manner similar to the cultural spread of new innovations found in humans. I will be answering your questions at 1pm ET – Ask Me Anything! Don’t forget to follow me on Twitter @LChittka!

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PLOSSCIENCEWEDNESDAY [R/SCIENCE](#)

Hi Reddit,

My name is Lars Chittka and I am a professor of sensory and behavioural ecology at Queen Mary University of London. My research focuses on the learning processes, the sensory organs and the social behaviour of bees, and their interactions with flowers.

I recently published a study titled "[Associative Mechanisms Allow for Social Learning and Cultural Transmission of String Pulling in an Insect](#)" in PLOS Biology. In this study, we discovered that bumblebees can solve a string-pulling puzzle, where they had to pull on a thread to retrieve a reward from an artificial flowers that was presented under a glass table, so that bees could see it but not reach without pulling the thread. Moreover, we found that inexperienced bees could learn the technique from experienced ones, so that the skill spread rapidly to a majority of colony members, in a manner similar to the cultural spread of new innovations found in humans. I will be answering your questions at 1pm ET -- Ask Me Anything!

Don't forget to follow me on Twitter [@LChittka](#)!

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Did you change the puzzle at any point? If so then how quickly/slowly did the bees adapt?

[Heathen15](#)

Change was part of the training procedure for many bees. Only two individuals solved the task spontaneously, without any stepwise training or observation of skilled bees. For the others, we trained them by gradually changing the difficulty of the task. At first, flowers were completely 'open access', then they were partially hidden under the glass table, then completely pushed under the table. Bees cope very well with this sort of change, where tasks change only moderately and difficulty increases slowly. A trick to put animals on the spot is a so called reversal learning test, where they have to learn that the opposite of what they previously learnt is now true. So for example, in one phase, blue flowers are rewarding and yellow ones are not, and after bees have learnt this, you switch the contingencies around. This can be very confusing for bees, especially if you reverse the associations several times. But if you do it multiple times, bees will pick up on the schedule on 'learn to reverse learn' very quickly.

Do you think that if you then changed the set up so the flower was accessible without string pulling, the bees would still pull as a kind of superstition?

[Inamo](#)

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That's an interesting question... but I'm sure that bees would pick up on this change very quickly. They are generally very good at figuring out the quickest path to a reward, especially if the task is easy (just landing on an open accessible flower). If however, we presented the bees with artificial flowers under a glass table, but without a string, they would certainly spend a great deal of time rummaging about at the edge of the glass table in an attempt to look for the string. And bees are certainly creatures of habit: for example, in one experiment, when we moved a flower that bees had visited multiple times, we found that bees would visit the learned location again and again, even after multiple failed attempts: Lihoreau, M.D., Raine, N.E., Reynolds, A.M., Stelzer, R.J., Lim, K.S., Smith, A.D., Osborne, J.L. & Chittka, L. (2012). Radar tracking and motion-sensitive cameras on flowers reveal the development of pollinator multi-destination routes over large spatial scales. *PLoS Biology*, 10: e1001392.

Smart bees! There must be all kinds of anecdotes about the bees' errands within your lab -- please share your favorite (or three).

Also, greetings to Dr Loukola!

[ketarax](#)

Sure! One observation is that some individual bees are always exceptionally smart. Some years ago we did an experiment that required us catching the bees in black film canisters on every departure and return to their nest (to weigh them). Most bees initially resisted, but eventually got used to it. One bee, however, learned to fly straight into the black container, even if we held it in the air several meters from the nest, and expected us to transport her back to the nest. -- In another experiment, I kept a bumblebee colony in a greenhouse. The greenhouse was sealed tight, since I wanted all the experience to occur with just the artificial flowers I had set up in the greenhouse. However, a few bees eventually came back with pollen from natural flowers - and I found out that they had discovered a drainage hole in the floor of the greenhouse, walked through a drainage pipe for about 2m, and then emerged on the other side to look for natural flowers. -- Wasps are very smart, too! On one occasion, one of my team members trained a honeybee to locate the correct visual pattern in a Y-maze, and a social wasp came along too. The wasp learned the task faster and also learned to exit the lab faster than the bee. And in the end the wasp killed the bee and then had the setup to itself... - I'll pass on the greetings! :-)

Hello Dr. Chittka,

Thank you for doing this AMA! I really admire your work.

As a one-time fellow bee researcher, one question that I find fascinating in both neurobiological research and in public perceptions of how brains work is the relationship between brain size and behavioral complexity or intelligence, and I enjoyed your publications on this topic. Do you have a favorite everyone-friendly explanation for how the tiny brains of bees can process complex behaviors and learning tasks? What quantitative or qualitative differences would you highlight between social learning in bumble bees and social learning in species with much physically larger brains, such as primates?

[neurobeegirl](#)

There isn't a single, easy explanation. In some cases, it looks as if in insects, single neurons can take on the tasks that are mediated by 1000s of neurons in vertebrates. For example, Martin Hammer discovered a neuron that, all on its own, appears to constitute the olfactory reward pathway in bees (whereas in the mammalian dopaminergic reward system, there may be 1000s of neurons involved in

this task. In other cases, there may be multi-tasking of single circuits in multiple tasks in the insect nervous system (see e.g. Niven, J.E. & Chittka, L. (2010). Reuse of identified neurons in multiple neural circuits Behavioral and Brain Sciences, 33: 4). In yet other cases, seemingly complex abilities might be mediated very simple neural connectivities (e.g. Peng F. & Chittka L. (2017) A Simple Computational Model of the Bee Mushroom Body Can Explain Seemingly Complex Forms of Olfactory Learning and Memory. Current Biology 27(2): 224-230). In terms of at least some forms of social learning, there might not be such a fundamental difference between vertebrates and invertebrates. Cecelia Heyes, for example, has made the point that many forms of social learning hinge on relatively simple forms of associative learning that are just co-opted into social processes in some animals.

Other than the fact that bees can solve puzzles, what is the coolest bee fact you know?

Also, do you think there is a difference between honeybees and bumblebees in this?

[invitroveritas](#)

Depends on how you define coolness... :-) There are many - in addition to the remarkable learning abilities, there are their strange sensory worlds - the fact that bees can see ultraviolet and polarised light for example, and use this for identifying flowers and navigating securely over many miles from their hive. One important difference between bumblebees and honeybees is that only the latter have a "language" - the "waggle dance" - a symbolic code by which they can tell each other, in the darkness of the hive, about the precise location of a rich flower patch they have discovered. No other animal (humans aside) has such a code, and bumblebees don't either (they just have a chaotic "slam dance" by which they alert other bees to the current availability of food, without passing on the coordinates). What is perhaps even cooler is the fact that honeybees use this dance communication system in a consensus building process when a swarm decides on a new location to live in. There's initially a lot of disagreement between scouts, but ultimately everyone in the swarm agrees on one destination. The process is described beautifully in Tom Seeley's book "Honeybee democracy".

Do you think that bees would be able to learn the task from observing other animals/robot doing the same?

[Goldragon979](#)

That's quite likely, so long as bees first had the opportunity to learn that these other animals or robots have 'meaning' for them (i.e. their presence is associated with reward). Darwin already suggested that honeybees could copy from bumblebees the technique of nectar-robbing (where bumblebees bite holes into the spurs of flowers as a shortcut to the nectar, and honeybees then use the flowers). We haven't experimentally tested whether this is true, though bumblebees can certainly learn from honeybees where to find the most rewarding flowers: Dawson, E.H. & Chittka, L. (2012). Conspecific and heterospecific information use in bumblebees. PLoS ONE, 7: e31444.

Hello Professor Chittka, thank you for doing this AMA!

I have a real love of bees, and their decline is naturally quite worrying.

My question is: Since people in urban areas are likely to bring in a constantly-changing and wider variety of plants every year, with each garden being slightly different, do you think the rate of skill transfer in "how to efficiently harvest pollen" may be greater in urban bee populations than in rural populations, and could this be tested?

Thanks!

[StonedPhysicist](#)

Very interesting question! Certainly generalist bees (such as honeybees and most bumblebees) that naturally visit a wide range of flowers, and arrive at their favoured ones by learning which are the most rewarding ones, are relatively well equipped to benefit from exotic flowers. But since, as you say, there may be only relatively few stands of some of these plants in any one garden, this will certainly keep bees on their toes, and in some cases force them to multi-task and visit multiple flower species (that may all differ in colour pattern, scent, and the particular motor patterns required to harvest pollen or nectar). We do know that bees need to learn the techniques to harvest pollen efficiently: Raine, N.E. & L Chittka. (2007). Pollen foraging: learning a complex motor skill by bumblebees (*Bombus terrestris*). *Naturwissenschaften*, 94: 459-464, but we don't yet know if a fine-motor skill like this can be learned socially from other bees. Some techniques, however, are certainly copied, for example nectar robbing, where bees 'steal' nectar from long-tubed flowers by biting holes into the tubes - Darwin already suspected that bees might learn this from other bees, and here it is confirmed: Leadbeater, E. & Chittka L. (2008). Social transmission of nectar-robbing behaviour in bumble-bees. *Proc. R. Soc. B*, 275: 1669-1674. So while it's not certain whether skill transfer is more in demand in urban areas, you are quite right that the small size and diversity of flower supplies may place higher demands on the learning skill of urban bees. This could be tested both by observing how many species of plants are typically visited in urban versus rural or natural habitats, and also by testing the learning skills of urban versus natural pollinators in the laboratory.

Is the physical task of pulling a string similar to any tasks that bees naturally do? I'm just wondering if having a task that is similar to normal behavior is easier for them to learn, or if it is a completely novel task.

[kerovon](#)

Good point - all animals are of course better at learning tasks that are closer to what they encounter in their natural environments. Bees are much faster at learning colours than cats for example - and that's because for bees (but not cats), colours play an important role in their daily activities of visiting flowers. -- In this particular case, we deliberately chose a task that is relatively far removed from bees' natural activities - we wanted to push them to their intellectual limits a bit! :-). There may, under some cases, be tasks that are somewhat similar, though: e.g. bees might sometimes have to pull debris out of their nest, for example. But this is still quite far from pulling on a string with the explicit purpose of obtaining a sugar reward.

This information was transmitted using the "dancing" behavior we see in bees right? Does this open the door to further studies into just how complex bee "language" is?

[versipelis](#)

Hi there - no, the dance communication system is unique to honeybees, whereas these experiments were done with bumblebees. While the dance "language" in bees is unique and extremely impressive, it has only relative few "words" - bees only communicate about the distance and direction of a food source from the hive, and the quality of the food. They cannot inform other bees about things other than location - so they cannot "talk" about the colour of flowers, or indeed complex tricks such as how to pull a string. The bumblebees in our study learned this without the experienced string-pullers making an active investment into passing on the technique. The learners just "scrounged" on the information provided, by observing the skilled individuals.

Do you have a video of this?

[gex80](#)

Sure... there are several that were published with the original paper on the PLoS Biology website: <http://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.1002564> ... and also on social media, e.g.: <https://www.facebook.com/theguardian/videos/577812755739825/>

Aren't bumble bees endangered now? Do you think their numbers will come back up?

[YELLIO](#)

It depends on the species... there are about 300 species of bumblebees globally. Some species are already extinct locally and possibly globally; many more are under threat. A few species seem robust in most regions, and indeed some are spreading in habitats where they are not native, since they have been introduced by humans for commercial pollination purposes. Fortunately, in addition to nudging policy makers, there something that everyone can do to help ailing pollinator populations: to plant flowers that benefit bees (rather than ornamental flowers that have no value to pollinators). There is some useful information about which flowers to plant here:

<http://www.sussex.ac.uk/lifesci/goulsonlab/resources/flowers> and here: <https://www.savelondonbees.co.uk/>

Thank you for doing this AMA! I was fascinated by your findings when you published the findings.

My question is: how does this change what we currently know about bees, and what does this new knowledge of how quickly they can adapt to a reward-based exercise imply in regards to regards to bees adapting to global warming?

Also, what would happen if you isolated some of the larvae after the bees had been solving string-based puzzles for some time (before they had a chance to visually communicate), raised them, and then introduced them to the puzzle? Would they exhibit the same initial learning rate, or would it be accelerated?

I just realised this is more than one question, so I do apologise!

[PencilinMyHair](#)

Thank you so much! It's not straightforward to make a link between an animal's intelligence and their ability to cope with global warming, though. Many species of bees are already under stress from habitat loss (meaning the loss of suitable flowers as well as nesting sites), pesticides, and diseases. Global warming will likely add to this, since more arid conditions mean fewer flowers in many habitats, etc. What's a bee to do, even an intelligent bee...? It's clear that a bee species that is narrowly specialised on particular flower species (and can't easily learn to exploit other species) will be in big trouble if it has to move north because of climate change, if that flower species is not available there. But generalists such as most bumblebees might do better, since they can learn to exploit new flower species (though they wouldn't have to pull strings for that...) -- As for your second question, we have not done such an experiment, but I suspect that direct observation is necessary for the skill to be passed on. That said, Martin Lindauer did some work where he trained bees to forage at certain times of day, then raised the larvae from such colonies ("early or late risers") in isolation and then placed them in new colonies. The bees hatching from the larvae then were early (or late) risers as well! When they were larvae, they might have picked up the timing from dancing bees that were vibrating the comb

as they danced.

Hello Professor Chittka, How complex is a bumble bee brain? Do other hive insects (bees, ants, wasps) have similar brain structures?

[Aximill](#)

The overall gross neuroanatomy is quite similar between the various clades of the Hymenoptera (i.e. there aren't obvious brain modules that exist in one species but not others). That said, there are of course substantial differences in the sizes of various brain compartments between species. The most important differences are likely at the microcircuit level, but they will be much harder to identify.

Why did you decide on researching the learning process of bees instead of more intelligent species? I always viewed them as pretty "dumb" and sensory-driven. Is it primarily because of swarm intelligence or what else is it that made you decide "I want to know more about how bees learn"?

[Finrod04](#)

Some years ago, I founded a research centre for biological psychology at my university, and was fortunate to recruit a number of outstanding scientists working on the intelligence of apes, corvid birds and parrots, and indeed on human cultural evolution (the ways in which ideas and technical innovations spread among human populations, in ways that parallel genetic evolution). I had always been working on bee learning and memory, and I guess there is a perception among my colleagues working on larger-brained animals that all the behaviour complexity we see in bees, impressive though it may be, is largely based on instinct. While bee researchers had long known that bees learn the location of their hive and flowers, as well as the colours and patterns of flowers (etc - all of this is not just sensory-driven but requires learning), there was a challenge for me: I asked what may have seemed an entirely mad question when we first started – could we get our small-brained bees to solve tasks that might impress e.g. a bird cognition researcher? Could we find some individual bees that would innovate and solve a difficult puzzle, and could these techniques spread through a bee population in a similar manner as in human cultural evolution, by more and more individuals copying the technique? The bigger-picture goal, though, is to explore just how much cognition you can achieve with how small a brain. This will give us information about the minimal neural circuits for any particular learning task, and how circuits in miniature brains can effectively multi-task to juggle a large number of behavioural skills.

Would you expect similar results if you changed the species being tested to the well-known European honeybee (*Apis mellifera*)?

[keithtamborello](#)

We don't know this yet - I have no reason to suspect that honeybees won't learn it, but someone should test it...

What was the most surprising difficulty with the whole experiment?

[Digletto](#)

Actually there weren't too many experimental difficulties... the nice thing about such behavioural work is that it's easy to see what works and what doesn't, so the feedback loops are quick: if a technique

doesn't work, you see it right away. That leaves lots of room for creativity. Anyone can do such experiments - you just need ideas. In terms of technology, these experiments could have been done 100 years ago. I'm happy that in this post-genomic age, where fancy and expensive technology is often fetishized, we can still do our work with a bit of plywood, cardboard, glass and some live animals.

What made you think about trying this experiment and what was your expected outcome?

[JoeRmusic eater](#)

I had been thinking about human cultural processes for a number of years, and wondering whether they really are as unique as they're made out to be. I remember sending an email message, some years ago, to the 1st author Sylvain Alem, saying if we can demonstrate something as unusual as string-pulling in the bumblebee, and find that it spreads by social learning, we'll have something really interesting. I also said that it's very unlikely to work... But fortunately Sylvain was happy to take that risk, and in collaboration with Clint Perry, they designed the paradigm and found quite quickly that indeed bees could be trained to solve the string-pulling task. That was by all means a big surprise, even though we must all have had an inkling that it wasn't entirely hopeless – otherwise we wouldn't have tried. But it was even more of a surprise that not only could bees be trained to solve this task in a step-by-step manner – but a small minority of bees actually solved the task by themselves, without gradual training or observing a skilled bee. 110 naïve individuals were given the opportunity to solve the task of their own accord; each of them were given 2 trials. Two of the 110 bees managed the task on their second attempt. While these two were clumsy and inefficient at solving the task, it showed that through persistent exploration and trial and error, some individual bees could actually solve the task by themselves. The final big surprise came in the context of social learning: we discovered that naïve individuals that would observe, from a distance, a skilled string-pulling bee, could subsequently solve the task by themselves. But we really didn't know that any of this would work when we started...

Thanks for the AMA, this is one of the more interesting studies I've read in a while. I've got two questions.

So it seems that the learning can transfer between bees within a hive but would you expect that information to travel between hives? Is there a mechanism for that to happen?

Do you have any more plans to test the bees with different, perhaps more complicated tasks?

[Collif](#)

Yes, since the observations of skilled string-pullers by uninformed bees happen at the feeding station (not in the hive) it is quite likely that the information could spread from members of one colony to the next, but we have not tested this yet. -- We are currently exploring whether bees qualify for simple tool use tasks, where they move an unattached object from one location to another, and place it in a correct manner to gain access to reward.

What was the reward for the bee? Are there higher and lower value rewards for bees, and if so, what's a bee's favorite reward?

[ajaxia](#)

The reward in our experiments is typically sugar solution (equivalent to nectar in flowers, but without the scent). Pollen can also be a reward. In terms of sugar solution, in general, the more concentrated it is, the better - until above 50 or 60%, it becomes so viscose that bees have difficulties imbibing it...

they also prefer large over small volumes of sucrose solution.

Fascinating research! From your anecdotes, it sounds like there are interesting phenotypic differences between bees (the "smart" ones and the regular ones). That's not what I would have assumed, given the highly collective nature of their society. I'm curious whether there has been any investigation of genetic markers of these differences.

How much genetic variability is there between bees from the same colony? As I understand it, they all come from the same mother (the queen), correct? How many of them share the same father (all of whom are, themselves, closely related)? Is there an estimate of how genetically similar, on average, any two bees from a colony would be?

[Scrupy7](#)

Most bumblebee queens mate only once, so all workers in the colony have the same father, and so in line with the classic haplodiploidy scenario, workers will be 75% related on average (so highly related but not genetically identical). In honeybees, queens mate multiple times, and so average, relatedness is lower. The genetic factors underpinning individual cognitive differences in bees have not yet been identified to my knowledge.

How do you train a bee to pull a string?

[knottj](#)

...described here: <http://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.1002564>

Hello Dr Chittka,

I am trying to read through all the questions before this AMA ends so apologies if this has already been asked: how do you mark or identify the individual bees in order to track their responses?

[drag0nw0lf](#)

We attach number tags to their backs with super-glue... they're the number tags that have been developed to mark queen honeybees