Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company’s public news and information website.

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the evolution of wings was concurrent with the evolution of the adult molt as the final molt. He postulates that mechanical problems that would be encountered during ecdysis of a winged adult confer a selective advantage for the loss of the ability to molt. This evolution was accompanied by the degeneration of the ecdysone-producing glands during or immediately after the adult molt. He also suggests that adult-committed epidermal cells may have become incapable of producing a new cuticle. However, this suggestion is not true for at least some insects because adults of the bedbug and the blood-sucking bug, *Rhodnius prolixus* [2], and the giant silk moth, *Hyalophora cecropia* [3], can form a new adult cuticle (usually without bristles or scales) if parabiosed to a molting nymph or pupa, respectively, or in the case of *Rhodnius* after implantation of the glands producing ecdysone [4].

The final chapter discusses in detail the two current theories on the evolution of metamorphosis: the pronymph theory of Truman and Riddiford [5,6] and the direct homology theory first proposed by Poyarkoff, later modified by Hinton and Sehnal, and most recently updated by Jindra [7]. Basically, the difference between the two modern versions is in the origin of the holometabolous larva. The pronymph theory hypothesizes that the holometabolous larva hatches as a free-living pronymph that can feed and grow through several larval instars, then metamorphoses into a pupa that is equivalent to the hemimetabolous nymph and finally into the adult. The finding showing that Broad, the holometabolous pupal specifier, is present in hemimetabolous nymphs and necessary for their sequential nymphal molting [8] supports this hypothesis. The direct homology theory posits that the post-embryonic nymphal and larval stages (instars) are equivalent in terms of their hormonal regulation by JH. This theory is supported by the recent findings showing that no JH is required for development through the first two post-embryonic instars when the insect is not competent to metamorphose, whether it be hemimetabolous or holometabolous, and that metamorphosis in both cases begins in the final stage with the decline of JH and its major effector Kr-h1. The discovery that JH application to embryos of hemimetabolous locusts [5] and crickets [2] caused cessation of growth and precocious differentiation, the opposite of the “status quo” action of JH in post-embryonic development of allowing growth and preventing metamorphosis [6,7], seems to be the point of controversy. Belles concludes this chapter with a proposed mechanism based on regulation of Broad by JH to explain the origin of holometabolous and points out experimental approaches that may help to resolve the differences among these theories.

The book concludes with an epilogue that summarizes major questions still to be answered in the study of insect metamorphosis and suggests some approaches to answer them. Overall, this is a very good book that provides graduate students and new workers in the area with a comprehensive introduction to the field as well as gives workers in the field both a historical perspective and an overall, up-to-date summary of current knowledge. I expect that it will stimulate further interest and study in this area.

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Q & A

Cat Hobaiter

Cat Hobaiter grew up in Lebanon, England and France. She has worked with primates in Uganda, and across Africa, for 15 years. She earned her PhD in 2011 from the University of St Andrews in Scotland, and today her group there concentrates on long-term field studies of communication and cognition in wild African apes. She continues to spend around half the year in the field and recently established a new field station in Uganda: the Bugoma Primate Conservation Project. She likes good coffee and bad science fiction.

What turned you on to biology in the first place? As a child, I loved trying to figure out how things worked — anything from broken appliances to animal skeletons was fair game. For a long time, I thought that I’d study physics: it allows you to explore how and why things work at every scale. I remember reading Hawking’s *A Brief History of Time* under the duvet with a torch and a dictionary when I was around 11 or 12, and my A levels included Physics, Maths and Mechanics but not Biology. I’d also always been fascinated by animal behaviour, but it really wasn’t until I was starting my undergraduate that I realised that it was something you could study as a science.

And what drew you to your specific field of research? I took an undergraduate Psychology class at the University of Edinburgh that included animal behaviour — it was the first time I came across the idea that evolution could shape not only our bodies but also our minds. That had me hooked! I wish that I could tell you that my career then followed a carefully thought-out plan, but much of it has been serendipitous. After graduating, a mentor introduced me to a colleague of his, Richard Byrne, in St Andrews. I popped up for a chat and a cup of tea and I ended up going out to study forest baboon ecology in Uganda for four months. It was one of those wild shot-in-the-dark projects: at the time, it wasn’t even clear whether there were forest-living baboons in Budongo, and it took me three months before I saw more than footprints. But I loved it, and for me fieldwork remains the perfect
combination of science, problem solving and outdoor exploration. We quickly realised that, until they started handing out PhDs with 10+ years of funding, the forest baboon project wouldn’t work, but Dick had been looking for someone to extend the work that he’d been doing on ape gesture to a wild population, and that was that — in the end, that cup of tea kicked off a whole career.

There are descriptions of gesture in wild apes in the field studies of the 1960s, but it wasn’t until the 1990s that interest really took off, when it became clear that non-human ape gestures share an important characteristic with human language: intentional use. Like all animals, humans broadcast information when we respond to stimuli: we yelp when we touch a too hot pot on the stove, irrespective of who is paying attention or even if there’s anyone there. But what we do with language is different: we intend to communicate a specific goal to a particular audience. Apes do the same with their gestures. For the next 20 years, most work focused on captive groups and, perhaps because of that, most gesture was described from immature apes playing. Ape research is founded on analysis of video data; there’s just too much going on to reliably detect all the behavioural subtleties without it. But there are few environments worse for video data collection than wild ape habitat: the rainforest is dark, the apes are dark and often 30 m up a tree, everything gets soaked and there’s always a branch in the way. In captivity, the apes are in nice, open, well-lit environments, they get good food, we get good coffee, and even if you turn up at 10 a.m. they are (hopefully!) all exactly where you left them the night before.

But it turns out that studying gesture in wild apes is incredibly worthwhile because ape gesture is not just about play: gesture is a fundamental part of their everyday communication. In the wild, all apes gesture — whether that be a 65-year-old grandmother or a months-old infant. A wild chimpanzee will gesture as often as she vocalises, and she’ll use her gestures to navigate all of her day-to-day social needs, from requesting grooming to asking someone to travel or to get lost! And because apes show their intentions through gesture, they give us an observable behaviour that is a window into their minds; a lens through which we can ask many other questions.

Who were your key early influences?
I’m a fairly old-school ethologist at heart: Tinbergen’s description of the study of animal behaviour as interviewing a species in its own language has always resonated with me. When we ask questions about other animals’ minds, we often ask how they are the same or different to our own. In doing so, we take the human-centric perspective, asking “can they do what we do?” But that’s only half the story: we also need to ask “can we do what they do?” Until we do that, we risk missing extraordinary species-specific capacities that are meaningfully distinct from our own (and likely some that are meaningfully similar but superficially different).

As humans, we instinctively understand that our distinct experiences lead to biases in how we think (we’ve all put our foot in it at some point by misunderstanding another person’s intention…). For me to explore what chimpanzees — or gorillas — mean when they are communicating to each other, I need to try to understand what it means to be a chimpanzee. Eliminating (or at least recognising) our human-centric biases is hard to do, but it allows me to ask what are to me the more interesting questions (and provides an excellent reason to spend as much time as possible in the rainforest or up a mountain).

Do you have a favourite paper or science book?
I love Smith’s ‘Message, meaning, and context in ethology’: four short, beautifully written pages that are as relevant to our study of communication today as they were when they were published in 1965.

What is the best advice that you’ve been given?
If Reviewer 2 ‘misunderstands’ your work, 9 times in 10 you gave them the space to misunderstand or misinterpret your meaning, so there is always something you can fix. Also, back up the backup.

If you had not made it as a scientist, what would you have become?
That’s tough! If I’m not working, you can usually find me climbing up something or pottering in the shed, but I have a sneaking suspicion that, no matter what I’d have ended up doing, I’d still have been trying to work out how and why things worked. I suppose that I think of a scientist as what I am rather than what I chose as my job.

What is your greatest research ambition?
I love the quote by Sydney Brenner: “to understand how all of this works we will need something more than merely lists of components… the great difference between the telephone directory and a Shakespeare play is that, while both have a grand cast of characters, only the play has a plot.” 

Photo: Courtesy of the University of St Andrews.
was talking about our DNA, but I think that it also beautifully illustrates what we have — and haven’t yet — done in studying animal communication.

We’ve spent decades focusing on describing the components of human and non-human communication: on the tools in the communication toolkit, the lists of signals in the repertoire, the rules for when to use or combine them. That gives us the grand cast of characters, but what about the plot? To understand human language, or chimpanzee or gorilla communication, we’re going to have to fundamentally change the questions we ask.

**Any strong views on social media and science?** Biology Twitter can be an amazing resource. In St Andrews, I’m lucky to be surrounded by a fantastic community of researchers all working on questions on animal minds, but often the majority of other scientists in our specialist fields or career stages are scattered around the world. Social media lets us do the obvious, such as share new research and jobs widely and with fewer barriers to access, but as a new PI it was also a fantastic support network: a sort of digital extension of our office coffee room with a broad spectrum of academic life experiences.

Social media might not be the right approach for everyone, but it’s important to find ways to break out of our science bubbles. While Twitter is not always an ideal place for nuanced debate (!), it can be a great way to start sharing our work more widely. Selfishly, what I’ve learnt through interacting with a broader audience about my research has helped me improve everything from teaching to grant writing. More fundamentally, our experiences as individuals impact the way we think and the questions we think to ask. If our goal as scientists is to understand the world around (or within) us, engaging broadly with different perspectives makes us better scientists.

**Which aspect of science, your field or in general, do you wish the general public knew more about?** No primate makes a good pet. Primates are very charismatic: they hit that primate makes a good pet. Primates are very charismatic: they hit that point just different enough, and with added ‘floofoof’ for good measure. That appeal means that they (and our research on them) get lots of public exposure and can mean substantial support for conservation. But their appeal also comes at a high price, in particular with the pet and ‘entertainment’ industries. The ‘entertainment’ industry is particularly problematic, but no matter how good your intentions, keeping a primate as a pet will cause substantial life-long harm to their wellbeing. Crucially, and perhaps counterintuitively, seeing primates in a human context, including just in close contact with humans, harms public perception of how threatened they are in the wild. With primate populations in rapid decline worldwide, everyone — including researchers and conservation organisations — needs to think hard about how we communicate our work to ensure we don’t encourage further harm.

**Do you think that there is too much emphasis on ‘big data’-gathering collaborations as opposed to hypothesis-driven research by small groups?** The oldest ape field sites, such as Gombe in Tanzania, are turning 60–years-old this year, but chimpanzees can live to 60 and more. All apes live long, socially rich, individually very distinct lives. They learn individually and socially. Their behaviour is impacted by genetics and socioecology. Until recently, all any one site — let alone any one scientist — had were snapshots of ape life. Big-data collaborations are not only about asking the same questions on a larger scale or generalising findings from a population: they are letting us answer questions that were impossible to ask without data at that scale.

But we can’t do any of that without smaller-scale hypothesis-driven research. My research group is currently putting together a big-data set on ape communication, comparing individuals, populations and species to unpick the different factors that shape gesturing. But, for example, to understand the influence of rank on gesturing across species, you need to understand how dominance is differently expressed in a chimpanzee and bonobo and gorilla. Without the species-specific understanding that has come from our smaller-scale work over the years, we could easily end up drawing superficial but meaningless conclusions from these big-data sets.

**What do you think are the biggest problems science as a whole is facing today?** Six months ago I would have said that my major concerns were about the structure of scientific funding and our ability to attract, support and retain young scientists. Primatology in particular needs to reckon with the systemic biases and colonial legacies that mean that research that largely occurs in the global south continues to be largely conducted by researchers from the global north. The COVID-19 pandemic will likely further worsen that situation, but it has also radically shifted the ground that I stand on as a primatologist and on which we all stand as scientists.

If COVID-19 gets into wild primate populations, we could face local- or even species-level extinctions, and field researchers have a responsibility to consider the impact of our work and presence on the communities around our study sites that often have limited access to healthcare and other resources. Primates are threatened on many fronts, but in this case what threatens them also threatens us. In Uganda, while a tough lockdown has been effective in controlling COVID-19 transmission, it has put local communities under increasing pressure and there has been a substantial increase in poaching and forest clearance. Disease spillovers happen where humans and wildlife come into increased contact. Which brings us full circle — with one pandemic creating the conditions for the next.

Trying to address the current crisis means having to radically rethink our actions as a global community and as biologists we get to be a part of that at every level: whether finding a vaccine or mitigating the circumstances that drive human–wildlife conflict. ‘Lucky’ is the wrong word to use when we have experienced hundreds of thousands of deaths to date, but another pandemic, and there will be a next one, could be far more contagious or far more lethal, so it also feels like we’ve been given a chance. Things that seemed impossible just a few months ago are already changing — if we’re rethinking what is possible in science, then let’s think big.

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