

set up to see who can catch the most. The Environment Education Foundation hosted its third 'lionfish derby' last month off Florida, outside the reserve, with more than \$3,000 in prize money for the team catching the most fish — 109 were killed.

In the waters around the Bahamas, which don't have the same protection as Florida Keys, more than 2,000 lionfish have been killed over the past two years.

"People have a sense that the waters they love are being invaded," says Renata Lana, a spokesperson for the National Oceanic and Atmospheric Administration. This year, the agency launched an 'eat lionfish' campaign aimed at creating a market for them in seafood restaurants and thus further prompting divers to hunt them.

NOAA calls the lionfish a "delicious, delicately flavoured fish" with a taste and texture similar to grouper, snapper or hogfish. A few restaurants in the US and the Caribbean are now serving it. But "it is tough for me to get," says chef James Clark in South Carolina. "Sometimes fishermen do not want to handle it on their boat."

Scuba divers are experimenting with new ways to eliminate the lionfish, developing new spears to catch the fish. "Six months ago, I hadn't seen one," says Jason Doty, in Florida. "Now I will kill 12 in one dive."

But, in spite of the battle, researchers fear that the lionfish could become one of the worst marine invasions of an alien species in history. We probably cannot completely eradicate lionfish. Only nature can do that, says one researcher.

Scientists agree hunting may help, but it won't halt the incredible population boom of lionfish that has seen densities increase 700 per cent from 2004 to 2008.

"The government is promoting lionfish as a do-good dish that helps to balance ocean ecology," says Lana. It is one of the few examples of a species that cannot be overfished. "It's one of the few fish people can eat out of existence with a clear conscience", she says.

Nigel Williams

Q & A

Lars Chittka

Lars Chittka is the scientific director and co-founder of the Research Centre for Psychology at Queen Mary, University of London. The centre is dedicated to the comparative study of psychological processes in animals as diverse as insects, fish, birds, and various species of mammals, including humans. With a focus on understanding how cognition functions in the economy of nature, the centre is unique in its tight interactions with evolutionary biologists and ecologists in the same department. As part of his PhD project, Chittka did seminal modelling work on the evolution of pollinator colour vision and flower signal evolution. As a postdoctoral fellow at Stony Brook University, he became interested in how cognition benefits an animal's daily activities, again using pollination systems as an experimental framework. Chittka remains fascinated with the question of how evolution shaped advanced cognitive capacities from the minimal neural circuitry available in insects. After an appointment as assistant professor at Würzburg University he moved to London, where he is now a Professor of Sensory and Behavioural Ecology. Chittka regularly appears in the media discussing, for example, why pollinators prefer van Gogh's Sunflowers and why bees' favourite colour is violet.

Were you always interested in insect psychology? As a teenager, I always read a publication called "Psychologie Heute" ("Psychology Today"), but I guess even then should have been more aptly entitled "Psychology Yesterday" — it didn't quite trumpet the rigorously experimental approach to psychology that we now advocate. Nonetheless, it was good enough brain fodder for a 16 year old. But I couldn't really see myself anywhere in a psychologist's office but on the couch, so I decided to study biology instead. I came to insects by chance — I started out studying Biology in Göttingen, a small and very traditional German university town. I was uninspired

with the nightlife there, and felt attracted to Berlin's subculture, so I asked a professor if moving to the Free University of Berlin would be a good idea. He replied that this would basically amount to career suicide — at the time, this university was more famous for far left-wing political activities than for scholarship — but he conceded that there was one good lab, working on bee learning behaviour and neuroscience. This sounded like a swell deal to me, so I packed my bags.

What do you find fascinating about insects? Some of the attraction of scientists to the insects, especially the social ones, is undoubtedly that they have 'invented' a number of feats that, to a non-biologist, might be considered uniquely human: agriculture, slavery, territorial wars, castes, division of labour, consensus building, a symbolic language, and teeming 'cities' with fantastic architecture. However, there is perhaps little scholarly information to be gleaned from such similarities: insects and humans are too distantly related for such comparisons to reveal anything but evolutionary convergence. To me, the primary fascination of insect sensory systems and behaviour is not in their similarities to humans, but in their alien-ness: the fact that insects perceive the world, process information, and interact with their environment in fundamentally different ways from humans is what makes them so captivating. And, of course, we cannot help but marvel at the complexity of behaviour and cognition generated by nervous systems that contain only a fraction of a percent of neurons compared with our own.

Do you have any particularly memorable moments in science? Here's an early one from my postgraduate studies. I developed computer simulations to find the theoretically optimal colour vision systems to code flower colours. The result was that these theoretically-derived, optimal colour coding systems were essentially indistinguishable from those really implemented in bees' eyes, and I at first interpreted this to mean that this meant bee colour vision had evolved for the efficient coding of flower

colours. Unfortunately, phylogenetic analyses later revealed that in fact it was the other way round — the kind of colour vision that bees have is several hundred million years older than the first flower. Flower colours had adapted to bee colour vision, not *vice versa*.

This work immunized me against the uncritical usage of modelling — biologists are often far too impressed by a match between a model and a biological phenomenon. Modelling is very useful for simulating conditions that aren't accessible experimentally — such as generating colour vision mutants that don't exist anywhere in nature. There is often very little biologically useful information in merely matching a model with reality. You might adjust parameters until you get the desired effect — the model works because you make it work; in other words, it's engineering, not science.

So then you started experimental work on bee cognition?

Yes, we did a rather outlandish experiment to explore whether bees could count. We erected series of coloured tetrahedral landmarks, each 3.5m high, in a large flat meadow, and the setup looked a bit like a project by Christo and Jean-Claude. Some of the bees solved the task, but many didn't, which alerted me to the necessity of studying interindividual variance in cognitive capacity.

Do you have scientific heroes?

Here are three: Jean-Henri Fabre as a founding figure in animal behaviour — his colourful descriptions of insect behaviour in the *Souvenirs Entomologiques* are absolutely peerless. Read, for example, his descriptions of parasitoid wasps as skilled neurosurgeons (they paralyse their insect prey with exactly three injections, one into each thoracic ganglion) or his admiration for hexagonal honeycombs as mathematically perfect solutions. One can't help observing that there is not a single vertebrate species with such wonderful behaviour adaptations. Only instinct? Yes, but still...

Then there's Charles Darwin, of course — not (just) for the *Origin*, but because the *Descent of Man* actually makes him the father of comparative cognition. Every scientist in the field should read the book — and

ask themselves if they're not just colouring in the map that Darwin drew in remarkable detail.

Finally, Darwin's apprentice, John Lubbock. He performed a number of experiments that might strike us as amusing from today's perspective: he played the violin to bees, for example, to explore their sense of hearing. When Alexander Graham Bell travelled to London in 1878 to demonstrate to Queen Victoria the benefits of the newly developed telephone, Lubbock instantly tested the new technology on ants — to see if they could transmit an alarm message from one nest to the other. So before the telephone was used for such mundane things as mass communication, it was put to good use in an entomological experiment. The result was negative, of course — but this ultimately led to Lubbock's discovery of a 'chemical language' in the ants — pheromone biology was born! So here we have two key ingredients of what makes a great scientist: the courage to explore genuinely novel territory (even at some risk of ridicule), and the instant recognition of how a novel technology might open up new horizons.

How do you recognise a great scientist?

Ultimately, as Otto Warburg used to say, the question is, what has he (or she) discovered? This question is answerable in prose only, not with any metrics. The current trend of assessing scientists by citation impact is not only terribly misguided, it actually encourages some very poor science. This approach is the scientific equivalent of the manufactured pop band — you identify a market niche, and then tailor your product to the demand to boost your sales. But are the Backstreet Boys really musically better or more influential than, say, Velvet Underground, because the former achieved greater mainstream popularity? Maybe not. In science, likewise, you can attract lots of citations if you give people what they want (typically a simple message, or a dogmatic stance on a vague subject) — but you don't really advance scholarship in this way.

What do you think is the biggest challenge in cognitive science today? I'm a science existentialist —

it's a senseless world, you set your own challenges. There isn't any particular branch of science that's inherently more important than any other. Thus, if you think the scientific study of yawning is more interesting than, for example, the neurobiology of consciousness, then so be it. But whatever you choose, at least make it a proper challenge. In comparative cognition, for example, the copying of concepts and methods from psychology, and adapting them so your pet animal can pass the test, is not an adequate challenge. The finding that 'animals can do it too' often generates plenty of press coverage, but in my view this is rarely intellectually challenging or scientifically insightful. It has been clear for decades that many animals (especially our closest relatives) can do some of the things that we consider intelligent in humans, and indeed Darwin was quite aware of that. But I think the focus on measuring animals against human standards is a bit one-dimensional. In fact, one might argue that some of the most exciting discoveries about unique animal abilities would never have been made had this approach been used throughout. Would von Frisch ever have discovered the bee 'dance language' if he had deliberately set out to find a form of symbolic communication in the animal kingdom? Would Lubbock have discovered UV sensitivity in ants if he had looked for a colour vision system that's exactly like humans'? Probably not. Rather than searching for charming similarities with humans, it is more promising to launch into the unknown and strive for genuinely novel discoveries.

How are we going to go about that?

I advocate more open-ended observations and more comprehensive, automated data recording in the behavioural and cognitive sciences. We need more data-driven (inductive) rather than hypothesis-driven research. Researchers in the 'omics' might achieve this, to some extent, as a by-product of recent technological advances: collect lots of data first, ask questions later. The good old Popperian approach is fine for zeroing in on particular questions, but this shouldn't be an authorisation for unfettered

experimenter bias. As Francis Bacon points out in the *Novum Organum* (1620), the bee combines the best of both worlds: “Empiricists, like ants, merely collect things and use them. The Rationalists, like spiders, spin webs out of themselves. The middle way is that of the bee, which gathers its materials from the flowers . . . but then transforms and digests it by a power of its own.”

Can you give a more concrete idea of what cognitive science should strive for? We need to understand the neural circuitry that underpins cognitive processes in more detail, not just because we really still don't understand how the brain works, but also to understand the evolution of cognitive capacity. ‘Intelligence’ is not a biological trait that can be mapped onto an evolutionary tree in any meaningful way. My intuition tells me that many types of information processing evolve relatively easily in the face of the relevant selective pressures, but we need to know how many neurons (and with which connections) are engaged in any defined cognitive feat, how many sequential stages of information processing there are, etc. Insects' small nervous systems should make it feasible to explore these questions at a very fine-grained level. Will we manage a comprehensive understanding of the neural basis of cognition in any animal in the next few years? Maybe not, but “it is more exciting not to catch a big fish, than not to catch a small one” (A. Szent-Györgyi).

Do you have any regrets? There's not enough time in a scientist's life for such indulgence. Can some of my colleagues in ageing research please ensure a doubling of life expectancy for cognitive scientists in the next few years? I'm only mid-career, and it's a bit scary to think what I haven't achieved in those two decades. There are only two more decades left until retirement, and two times nought is ... — oops. Better get back to work right now!

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Quick guide

Dictyostelium

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What is *Dictyostelium*?

Dictyostelium discoideum (*Dicty*) is a social amoeba that lives in the soil and feeds on bacteria and other microbes. Dictyosteliida is a distinct branch of the eukaryotes, separate from plants, fungi and animals. The cells lack a cell wall and resemble animal cells in organisation, except for the presence of a contractile vacuole.

How can an amoeba be ‘social’?

Dicty is described as social because in times of starvation, individual amoebae aggregate to form a multicellular mound, containing up to a hundred thousand cells. The aggregate undergoes differentiation and morphogenic changes before maturing into a fruiting body which consists of two main cell types: spore cells, which are resistant to temperature extremes, desiccation and digestion, and stalk cells, which form the ancillary structures supporting the spore head (Figure 1). One interesting intermediary structure is the slug; during this stage, the aggregate moves collectively, responding to light and heat stimuli in order to find favourable conditions for fruiting body formation. This response to starvation is referred to as development and by going through this social, multicellular phase, the population dramatically increases their chances of surviving unfavourable environmental conditions.

So how do the cells move? *Dicty* amoebae are intrinsically motile and generally move using what is appropriately termed as amoeboid movement, producing actin-rich pseudopods at the front of the cell and using myosin to contract the rear. Amoeboid motility is also seen in neutrophils and tumour cells in animals; however, *Dicty* is flexible: it can also move using hydrostatic pressure-driven, actin-free extensions (blebs), or in a

keratocyte-like manner, with a single, flat, actin-rich lamellipod extending in the direction of movement. It thus displays, in one cell type, three of the major ways in which animals cells move.

How do the amoebae know where to go?

Amoebae are chemotactic: they can sense gradients of certain chemicals and move along them. *Dicty* is known to chemotax to two chemicals: folic acid, which is released by bacteria and used in the hunt for food, and cAMP, which is released by amoebae during starvation and used to find each other during aggregation. Cells have evolved a relay mechanism in which cAMP stimulates its own release, thus forming waves that can propagate through a field of responsive amoebae (Figure 2). Amoebae respond to cAMP gradients by polarising: creating a leading edge and a rear with different sets of lipids and proteins defining each pole. A classic example of this is the accumulation of PI(3,4,5)P₃ at the leading edge. After polarising, amoebae begin to move up the gradient of cAMP and are extremely sensitive to even shallow concentration changes — they can detect as little as 2% difference across their length.

How cells are able to sense and interpret a gradient is a major question in biology. It is widely accepted that the core features of the chemotactic signalling process and machinery are conserved from *Dicty* to mammals. *Dicty* has therefore become a very popular model for studying chemotaxis, because findings in *Dicty* often translate to the directed migration seen during the immune response, wound healing, embryogenesis and in tumour cell metastasis.

What can we learn from its development? In *Dicty* development, multicellularity is achieved by aggregation of pre-existing cells and not by division of a zygote or precursor cell, which allows the study of development in isolation from the cell cycle and cell division.

Cell fate is first determined early in development, with pre-stalk and pre-spore cells arising randomly in a ‘salt and pepper’ pattern at the mound stage. Fascinatingly, this occurs