AFTERTHOUGHTS

Let us start at the small end, with the nerve cells. Electrophysiology is an attractive technique for mechanistic analysis. When successful, the data flow from the electrodes and amplifiers. To explain even a little of the behaviour, however, electrophysiology requires a thorough knowledge of the neuron anatomy. One can go only so far with these methods and then find that the different kinds of data do not easily fit together. Neurons are relatively simple, but their combinations are devilishly difficult to unravel. The bee has small neurons, as yet obscure neuron anatomy in detail and behaviour with too many interacting causative agents for total analysis.

Next come the bees. Bees are unique for the study of olfactory and visual behaviour because they readily learn to use these stimuli to come for a reward. Analysis of the behaviour alone leads to a map of the formal interactions that explain this particular behaviour of bees. This map can look like the gross structure of the nervous system. This map of interactions then guides the anatomist and electrophysiologist towards the identification of the real map of signal transmission, possibly by using large tropical bees.

Next come the investigators. They need many skills, especially the experience to spot error. Students need to learn fast and thoroughly, but select what they want for themselves; read all the literature and take notes and notice gaps and anomalies that they would like to investigate. They need to think straight and to separate the reported experimental data, which are usually boring but correct, from the fanciful thoughts, discussions, postulates and theories that relate to the data, but might be misleading. Most science in this world is armchair or media science, but real discovery depends on the nuts and bolts, the nitty-gritty, the nose to the grindstone, with an observation every day, on the job.

It is a great shame that the most reliable accounts—the critical scientific reviews by experts—are scattered in expensive subscription journals. They should be available freely because the curriculum lags behind the frontier of knowledge, the textbooks are always out of date and perhaps the teachers are as well.

Turning now to the world of thought, philosophy and theory, it is clear from the preceding chapters that advance is premeditated but particular discoveries usually emerge from a series of experiments in which many interesting facts turn up. Then thought is applied, sometimes for a long time, even years, before there is any conclusion or an idea for a new experiment. At this stage, it is obligatory to think about the problem all the time. Advances originate mostly from projects that have lasted many years with secure funding. After the real work is done, the so-called philosophy of science appears as armchair or media activity. The actual experiments are soon forgotten among the talk and print about the implications and extrapolations by the chattering classes.

You might have noticed that my idea of analysis of behaviour is to aim to find a model or description of the mechanism in terms of the components that are likely to be involved, not in terms of concepts that are invented by intuition for this or similar occasions. At every step, testing the trained bees to discover what they really detected with their eyes has validated the postulated mechanism. So, I did not analyse 'innate' responses in terms of 'drives', but in terms of coincidences of responses of feature detectors, cues and labels that were separated, identified and characterised. Bee vision is unique and borrowed terminology is misleading.

Those who observe and describe the performance then dream up a theory or a mechanism that might attract media excitement, but usually they drive the topic into a morass of untested assumptions. Those who study mammals or birds do not have the luxury of hoping for a mechanistic explanation, so they use the terminology and intuitive concepts of cognitive science, mathematical models or the nerve nets of the connectionists, ignoring the possibility that these are entirely fictional and misleading. That effort leads to much discussion and wastage of time.

This divide between intuitive ethology and mechanistic comparative physiology can be traced back to the conflict between Kantian principles, as taught in countries that were conquered by Napoleon (roughly), and empirical principles, as taught in the English-speaking world (roughly). For obvious reasons, research on bee vision has suffered disproportionately on account of this legacy.

What did the analysis of bee vision teach us, besides the basic principles of a visual system of medium complexity with a small brain? We discovered the kind of system. The memory mechanism is not like wax that takes up any shape, but is a set of independent preformed boxes that can be ticked, and when the same combination recurs, the place is automatically recognised. Bees have no general concepts of texture, shape or topology but only a memory of cues in immediate past experience. Bees remember cues and places, not patterns or shapes.

The historical approach warned us of errors of thought, dangers of language and failures of successive paradigms. Bee vision, however, illustrates how the information in a picture or panorama can be greatly reduced and yet be recognised by a simple mechanism. It shows also that the evolution of bee vision has reached a level where no more processing can be done without the reassembly of the pattern, which requires vast extra processing power. Also, the bee has a seeing system, for large or small visual fields, that has been evolved for the recognition of places on a large or small scale, with minimum components and weight, which might be useful for machines with computer vision.

Finally, what of science as a grand and infallible discipline that is essential for saving the future of humankind? The tracks of those involved in the minute topic of bee vision do not appear to lead in that direction. Their blind alleys explored, adherence to ineffective methods, failure to consider and repeat the works of others, ignorance of the literature in languages other than their own and unwillingness to change their opinions all look like typical conservative acceptance of the status quo and preference for a discussion instead of another experiment. Others persist, however, and yet others become committed. They read more, look again at the natural world and think more deeply. Science follows a circuitous path, highlighted here and there by a flash of brilliance, forever attracting enthusiastic new students and charting an unexpected path, forever inadequate to comprehend the whole because there is so much more to be discovered.