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# The Cognitive Animal

## Empirical and Theoretical Perspectives on Animal Cognition

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# 7 Raven Consciousness

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In my most recent research I tried to figure out if ravens (*Corvus corax*) can think; that is, if they have the ability to execute the best solution to a simple but at least novel problem without first being programmed to do it (such as by purely hardwired responses or by trial-and-error learning). Before starting this project, I had not given much thought to the idea of trying to collect data on what may or may not be occurring in an animal's mind, largely because I was skeptical of being able to get such results. My intent here is to provide an overview of a research program that spans a range of taxa with which I have had experience, and to provide my assumptions and approaches. The results, conclusions, and steps in the research have been published elsewhere.

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## Beginning with the Bees

Starting with insects in the 1960s, I tried to solve questions that involved primarily physiology and evolution, such as: Is body temperature regulated, and if so, how and why? Relatively clear answers could be found through long-standard methods of measuring body temperature, blood flow, energy expenditure, heart and breathing rates, heating and cooling rates and so forth, in the context of comparative physiology. However, when trying to solve puzzles of evolution and adaptation, the ultimate reference is the field, where there is no clear boundary between physiology and behavior. The laboratory situation, because it is controlled and thus contrived, allows discrete answers to the most basic, fundamental questions about mechanisms that, like bricks, build the whole animal.

Thus, at one kind of flower, in one kind of weather, under one condition of the colony, a bumblebee might precisely regulate its thoracic temperature to within a degree of 42°C and have a variable abdominal temperature of 25–30°C.

Change any of these parameters, and the bee's thoracic temperature might be 30°C and its abdominal temperature 10°C, or both temperatures might be regulated near 35–40°C (Heinrich 1979b).

In another taxon the data would most likely be radically different, despite similar underlying generalities that apply to both. Details matter profoundly. The complexity that was revealed in insects hinted at a sophistication that seemed unanticipated and surprising, but it ultimately made sense when seen in terms of the larger picture of adaptation (Heinrich 1993).

Not every potentially relevant factor could be measured. For example, it seemed that a bee exhibited something akin to excitement when it found flowers with a high nectar content. Its breathing rate and body temperature shot up immediately; it flew much faster; its flight tone went from a hum to a buzz; it became more selective in flower choice; and it made more frequent foraging trips. The change of behavior clearly and unambiguously registered that the animal could measure food quality, but whether it might know this consciously, as opposed to reflexively, was of no relevance to the questions I asked or felt I could ask. The behavior could be accounted for in terms of rote learning superimposed on innate programming (Heinrich 1976, 1979b; Heinrich et al. 1977). Bumblebees have a relatively open program concerning which flowers to visit and how to manipulate them to most quickly extract either pollen or nectar (Heinrich 1979a), but within a few flower visits they learn to heed specific flower signals and adjust their foraging routes and flower-handling skills accordingly.

The bees' behavior was, after all, predictable, and much like their physiology, the responses served specific functions either in the context of a predictable environment or predictable changes

in the environment. They were ideal organisms for demonstrating often highly intricate evolved responses, including specific learning tendencies, to all sorts of environmental contingencies. Although I saw no evidence that their sometimes complex responses could not be accounted for by programming alone, there was, of course, no objective reason to either exclude or accept the possibility that they consciously “knew” what they were doing after they were doing it.

In the whole animal, various responses are integrated and make sense in terms of a larger program. Thus, the energetics of thermoregulation is a component of foraging behavior, because thermoregulation is primarily used for foraging (Heinrich 1979b). In bees, furthermore, the foraging responses of individuals tie in with the colony's economy and cannot be fully understood except through the perspective of the colony's response in the context of a specific environment. For example, honeybee workers communicate the location and quality of potential food sources to hive mates. Bumblebees, who are “equally” social, do not. The difference is that honeybees, which originated in the tropics, are adapted for harvesting from clumped resources, such as flowering trees. Bumblebees, on the other hand, are tundra- or taiga-adapted animals who forage from widely dispersed flowers where communication is of less importance to the hive's economy (i.e., the queen's reproductive output).

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### Going to the Birds

This is where the ravens came in. Ravens are well known to be solitary and territorial breeders (Boerman and Heinrich 1999). As such, they should have no apparent advantage, like honeybees, in communicating the locations of food bonanzas. However, since I was myself attracted to a ravens' feast by the birds' loud activity, I was impelled to test whether their vocalizations attracted other ravens. Indeed they did. That

is, other birds came to playbacks of vocalizations and then also fed; strictly and objectively defined, the food was being shared. To me, whether the food was being shared “willingly” in the sense of “deliberate” recruitment, or whether recruitment resulted “inadvertently” or from the fact that the birds behaved mindlessly (without knowledge of consequences) but, as in the bees, in a way that was adaptive, was at that point not a relevant question. Other questions had to be answered first: (1) Does their vocal activity draw in others? (2) Do those that are drawn in get to feed? (3) Is there an advantage for those whose vocal activity attracts the others to have them come and feed? The psychological underpinnings of their behavior were surely interesting, but they were out of my realm as a behavioral ecologist.

As in the bees, sharing behavior among ravens could evolve by natural selection. For example, there would be some advantage for ravens to share very rare superbonanzas if they all did it. The biggest theoretical hurdle to this idea was that there seemed to be no mechanism for ensuring “honesty” in what would involve altruistic behavior, given that the raven crowds are not likely to be groups of kin or closed flocks of individuals who know each other and would, furthermore, remember favors and be able to play tit-for-tat.

The research that ensued to try to decipher the ravens' sharing behavior was physically demanding, but perhaps the intellectually most rewarding for me so far. I knew that within the birds' overt behavior lay a huge enigma (Heinrich 1989). At the heart of this puzzle was the question of how or why sharing among strangers, or near strangers, could occur on the basis of self-interest. There had to be an immediate advantage for attracting others to the feast. It turned out, of course, that there was: The sharers were juveniles who got access to new, untested, and hence feared food and/or food defended by more dominant adults (Heinrich 1988; Heinrich and Marzluff 1995). Given this advantage, the other and perhaps later even main advantages (such as

sharing the risk of not finding food) could be easily added on as “riders.” Recruitment and sharing occurred (Heinrich and Marzluff 1991) even in the unlikelihood of any psychological willingness to share (Marzluff and Heinrich 1991; Heinrich et al. 1993) and it occurred with non-kin (Parker et al. 1994), i.e., without kin selection. These data thus closed the loop on the problem I set out to solve.

“Cognition,” used in the sense of at least some conscious knowing with resultant purposive actions, then seemed like a possibility to think about. I had not credited bees with knowing or being conscious of the consequences of their waggle dances and thus performing them because they anticipated the positive consequences (i.e., not doing them if the situation were manipulated to cause negative consequences). Why? Largely because this scenario presupposes that they not only get satisfaction from dancing as such, but that they also get a reward from the consequences of their dance, i.e., seeing others rush out of the hive to forage at the source indicated. Not crediting bees with such—to them—probably superfluous powers, I would therefore not waste valuable research time hoping for positive results in trying to test such a scenario. With ravens, on the other hand, there is a difference—a huge difference. Close observation of various pet birds since my childhood has acquainted me with their emotional nature, a nature that is presumably adaptive (by rewarding fitness-enhancing behavior). Might not a raven be emotionally rewarded if it attracts others and makes it easier for them to feed? And might it therefore also not be motivated to recruit because it anticipates the same psychic and hence later material rewards?

I could not and have not eliminated certain aspects of cognition from the mechanism that we have elucidated by which ravens recruit strangers to food bonanzas and share the food. I do not know what the birds intend or are consciously aware of and what behaviors are reactions to stimuli. However, I am thrilled that sharing can

be explained without invoking any motive for sharing, because that makes it all the more remarkable and rational. It is much more convincing and elegant to find a mechanism that allows cooperation to occur as each individual attends to its immediate interests without having to invoke purposive logic (which all too easily can be incorrect in the long term since it is subject to faulty or incomplete information). Nevertheless, this in no way precludes conscious involvement, even though the latter is often a detriment to efficient or rational responses (such as in gambling, for example).

The logic of this behavior (i.e., seeing what is out of sight) is always time bound; there are instant or immediate consequences, consequences hours or days later, and potential consequences for breeding. Awareness in terms of consciousness, if it is present, could be used for deliberate planning for almost any time span. But the first and basic premise of logic is that steps can be tried out in the mind (Heinrich 1996, 1999) and mistakes corrected (see Allen and Bekoff 1997) to achieve an anticipated outcome. How far into time consciousness may extend the reality perceived by any one animal is, however, less relevant to me than experimentally determining whether awareness, as opposed to programming, plays any role for any time span at all, in any animals other than ourselves.

Bees cannot rely on conscious planning for the future in storing pollen and honey, etc. (what if some forget the locations?) anymore than any animal can safely rely on having sex solely on the rational basis of trying to produce offspring. The ultimate rewards must be subservient to stronger, move immediate rewards when the intervening steps are long, arduous, and complex.

On the other hand, it may be quite difficult to preprogram a squirrel to choose the best route through unpredictable mazes of branches to a nut. Conscious planning by mentally trying out a number of possible routes would likely be simpler and more reliable. Even jumping spiders appear to be capable of pursuing prey that is

out of sight when they invade the webs of other spiders (Jackson and Wilcox 1993, 1998); they use indirect routes and change their tactics as required.

My first intimation that ravens have some sort of awareness of immediate consequences, which is necessary for conscious planning, that would then guide their actions concerned their food-caching behavior (Heinrich and Pepper 1998). Since I had numerous birds in a large outdoor aviary, it was an education to observe their interactions. Bees could, through programming, execute impressive behaviors, but the ravens acted as though they could gauge the results of their actions even before they executed them; they altered their responses moment to moment, depending on what was happening. When some birds went out of their way to bury excess food, others tried to follow them even though the food was carried out of sight in the gular pouch. The followers (if subordinate individuals) acted surreptitiously, and they did not venture near the others' hidden food until the latter had left the area. The cachers (if dominant) in turn either attacked the raiders (but not others) when they came near the caches, or relocated their caches after they had been watched.

Nevertheless, as much as all of this behavior looked as if each bird knew what the other was going to do, it was still possible that the birds did not "know," in the sense of anticipating others' actions, until after they had taught themselves or had learned from experience. Of course, as in our own learning behavior, the birds may become conscious ("knowing") after learning the consequences of specific actions, so the conservative criterion of a test of cognition (knowing without prior learning) was not met. Nonetheless, given my day-to-day observations of the ravens, I eventually wondered if they might know something even though they had not learned it or had not been genetically programmed to know it. In short, I wondered if they could go through behavioral steps in the mind without also committing the body to the same steps first. If so, they

could perform the equivalent of trial-and-error learning in their heads, thereby avoiding the commitment of many errors.

It would not have occurred to me to present naive birds with a test involving food dangled from a perch on an almost meter-long string if it were not for my close observations of ravens caching, which sometimes suggested deliberateness and hence potential awareness. The food on a string puzzle (Heinrich 1996, 1999, 2000) was ultimately presented to a series of different ravens that had been reared from nestlings.

Prior to the test, these birds had never seen food or some other object dangled by a string, so that I could examine the details of their behavior on their very first exposure. Could they perform dozens of consecutive steps that had to be executed in a very specific sequence? Could they reach down from their perch, grasp the string, pull it up, lay it on the perch, step onto the string before releasing it with the bill, then apply variable pressure to hold the string fast to the perch while reaching down again and repeating the exact steps several more times in succession? Completing the whole task would require that they get a psychic reward not only from anticipation and/or eating the food, but also from completing each of the proper intermediary steps in a sequence that made their ultimate eating of food more likely. In short, no satisfaction could be gained from proximally unrewarding steps unless the ravens realized (i.e., understood) that what they were doing contributed to their objective (Craig 1918; Timberlake and Silva 1995).

Furthermore, with this test, I could cross check what they knew or did not know by prior training to say, red string, and seeing if they were then conditioned to respond to red string or would preferentially pull up food provided for the first time on a green string. The strings could be crossed to see if the birds' concept of reaching the food was to pull up the string "above food" or "attached to food." I could arrange the string so that they had to pull down on a string to have food come up. I could determine if they knew the

food was attached to a string by forcibly chasing them off the perch after they had pulled the food up to see if they would fly off with food that was tied on.

In short, the string test provided opportunities for obtaining a wealth of information where the relative contributions of innate behavior, learning, and cognition could all be at least partially teased apart. Obviously any one behavior contains some aspects of all three, but my main objective was to be as conservative as possible, to see if one could rigorously prove that at least some cognition involving consciousness was involved. The results (Heinrich 1996, 1999, 2000) could not be plausibly explained by the alternatives (random chance, rote learning, or innate programming) as sole explanations for the ravens' problem-solving behavior.

Future work should include other birds, especially other corvids. Other birds with similar body construction should be physically just as capable as ravens are in performing the same task. Can they solve the same puzzle? If not, then why not? Future work will also test whether ravens can keep track of objects that are out of sight, a prerequisite for conscious planning. We already know that ravens routinely keep track of food that others (other ravens and humans) hide. But can they project the path of a moving object that is out of sight (such as a rodent moving through an opaque tube)? By these and other tests, conducted with a variety of taxa, we hope to elucidate one of the perhaps most variable phenomena in the animal kingdom, the ability to solve problems by the application of consciousness, which has eloquently been suggested by the numerous animal studies summarized by Griffin (1998).

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