ANIMAL SENTIENCE
AN INTERDISCIPLINARY JOURNAL ON ANIMAL FEELING

Mehrkam, Lindsay R. (2019) A behavior-analytic approach to understanding octopus "mind". *Animal Sentience* 26(12)

DOI: 10.51291/2377-7478.1491

A behavior-analytic approach to understanding octopus "mind"

Commentary on **Mather** on *Octopus Mind*

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Abstract: Mather makes a convincing case for octopus sentience based on a lot of evidence of their complex learning capabilities. It should follow from Mather's findings that these intelligent invertebrates are worthy of welfare considerations, just as vertebrate species with similar capabilities are. I provide a complementary environment-behavior analysis of how we might understand the world of the octopus more straightforwardly, borrowing from Mather's examples, to show how to promote opportunities for complex learning and species-typical behaviors in the octopus.

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Mather's comprehensive account of the behavior and the perceptual world of the octopus leaves little doubt that they are intelligent, sentient, and capable of a range of complex learning about their environment. Many of these capabilities are also evident in other species that are already accorded higher welfare standards. Mather carefully considers a case for an octopus "mind." The existence of a mind is not necessary to establish that these animals are complex learners, worthy of welfare considerations. That we can directly observe them engaging in a wide range of intricate, voluntary behaviors — and learning about the consequences of those behaviors — is clear and convincing evidence. I offer here a more parsimonious, behavioral explanation of the range of learning capabilities exhibited by the octopus that may generalize to applied settings.

Environmental Antecedents and Consequences of Octopus Behaviors

In the study of operant behavior (voluntary behavior modified by its consequences), the fundamental unit of analysis is the three-term contingency, consisting of a behavior, its antecedents, and its consequences (Moxley, 1996). Antecedents are events that occur immediately prior to the behavior, and consequences are events that occur immediately after. A range of potential antecedent and consequent events for a selection of octopus species-typical behaviors (based on Mather) is presented below:

Antecedent	**Behavior**	**Consequence**
Change in substrate; presence of threat and/or availability of prey/mate	Skin color changes (camouflage)	Increased likelihood of obtaining prey/food; avoiding threat or predator; increased likelihood of copulation with mate
Presence of threat	Dark eye contrast	Avoidance of/escape from threat or predator
Presence or availability of prey	"Passing Cloud"	Increased rate of movement; closer proximity to prey; increased distance to threat
Availability of prey	Extending/grasping with arm/tentacles/suckers	Obtaining and consuming prey
Presence of threat and availability of suitable shelter	Hiding	Avoiding threat or predator; reduction of stress response; increased likelihood of obtaining prey

My explanation of these complex and impressive behaviors should not be misinterpreted as an argument that cognitive, internal processes or private events are not occurring within the octopus; rather, I argue that there are advantages to explaining behavior in the context of their antecedents and consequences. First, it provides a relatively straightforward way to identify the observable environmental events that influence behavior; this allows us to design environments that will promote these behaviors. Second, we can see that these are not merely stimulus-response relations but rather *voluntary* behaviors that are products of learning about consequences in the animal's environment (Delprado & Midgeley, 1992). This is already strong evidence that the octopus is sentient and worthy of good welfare standards. A third benefit of understanding behavior in this way is that it demonstrates that octopuses engage in learning that results in the avoidance of aversive events (e.g., hiding, "Passing Cloud," skin color changes) and that increases the likelihood of appetitive outcomes (e.g., copulation, consumption of prey, stress reduction) — further evidence that they are sentient. It can serve the animal to analyze whether these behaviors are the result of more basic behavioral processes with which we can explain *how* octopuses learn without inferring unnecessarily complex constructs. This can lead to a better understanding of octopus capabilities and hence to ways to arrange their environments to promote their welfare.

Behavior-Analytic Approach to Enriching the Octopus "Mind"

In animal husbandry, environmental enrichment is used to enhance physical and psychological wellbeing by promoting opportunities for species-typical behaviors, novel sensory stimulation, and more behavioral choice (Shepherdson, 1999). There are many studies on enrichment for charismatic mammalian and avian species, but effective enrichment for invertebrates is seldom systematically studied, as Mather notes (p. 15).

Below are some examples of cephalopod enrichment strategies and behavioral goals for each, based on Mather's review. Considering behavior-driven enrichment in this way can help promote opportunities for octopuses to express species-typical behaviors and engage in complex learning in artificial environments:

Behavioral System or Need	**Behavioral Goal (Established Beforehand and Evaluated)**	**Enrichment Strategies**
Motor	Locomotion of body/appendages; moving about different areas of enclosure	Provision of new structures/décor or arranging them in different ways around environment
Tactile	Grasping with tentacles or use of water "jetting" (may include "solitary play")	Provision of puzzles, Lego blocks (Kuba, Byrne, Meisel, & Mather, 2006), floating pill boxes (Mather & Anderson, 1999) or coconut shells (observed in wild octopuses, used to hide in)
Visual	Visual or ocular stimulation or "Passing Cloud"	Provision of mirror (Mather, Carere, Fiorito, & Anderson, 2018)
Foraging	Food-seeking behavior and successful consumption	Provision of live prey in puzzles or jars

This list is just a sample; an enrichment strategy could target multiple behavioral goals or go beyond this list. Reinforcement-based training could be enriching for captive animals; octopuses could be taught to collaborate in their care (e.g., station them in or target them to a specific area for feeding, train them to present body parts for routine medical checks or examination). Cognitive tests could serve as enrichment. Mather notes that octopuses "made more Mantle-Up challenge displays to conspecifics and more Passing Cloud displays to the mirror," although they did not pass the mirror self-recognition task (p. 6). Mirrors might serve as visual enrichment. The methods or stimuli to test for "tool use" or "self-awareness" might also be useful for welfare.

Mather notes that octopuses are flexible learners. They may habituate to frequently presented stimuli and instead try out different ways to obtain an outcome when a previously reinforced behavior is no longer effective. This is called *extinction-induced variability* (Neuringer, Kornell, & Olafs, 2001); it might help in evaluating whether an enrichment or training strategy is effective or the reward is of sufficient value to keep responding. Many other applications from the experimental analysis of behavior are available (Tarou & Bashaw, 2009) and would be well-suited in creating welfare-positive environments for octopuses.

Good welfare must be a high priority for these intelligent invertebrates, as it is for vertebrates. If an animal's environment fails to provide opportunities for species-typical behaviors and for the complex forms of learning of which octopus are capable, then scientists, industry professionals, and society as whole must question whether using them is ethical or warranted. Mather's contribution provides us with a strong start in making informed judgments.

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