

# Consciousness explained or consciousness redefined?

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Barron and Klein (1) define consciousness very narrowly, excluding most of the attributes commonly associated with it (e.g., self-awareness). By limiting the definition to a form of information processing, they find that insects qualify. However, just to put this conclusion in perspective, by the same definition, some robots are also conscious and capable of subjective experience. Autonomous, self-navigating robots with motivational circuitry [e.g., (2)] fit Barron and Klein's definition of a conscious entity (1). These robots create an integrated "neural" simulation of themselves in space and use appropriate internal and external information to do so, and their behavior can be influenced by their motivational state (3). Like a bee, these robots can actively hunt for things beyond their immediate sensory environment, something that the Barron and Klein (1) argue is a key requirement for subjective experience. These robots often use biomimetic neural structures, such as central processors with feed-forward, feed-backward, and recurrent connections. These artificial brains allow robots to integrate information, have motivational goals, direct attention to salient environmental features (i.e., exhibit selective attention), and make appropriate behavioral choices (3, 4). Although these examples of artificial intelligence (AI) show impressive abilities, even the AI community does not consider them as examples of consciousness (3).

The analogy between circuits within the insect cerebral ganglion and vertebrate midbrain is interesting,

but the enormous difference in neuronal number between the two raises the possibility that some elements that may be critical for consciousness are missing in insects. For example, insects do not appear to have circuits that subserve emotional behavior in the same way that vertebrates do (5). Insects appear to be under greater selective pressure than vertebrates to reduce the cost and size of their brain (6). This pressure probably reduces selection for traits such as subjective experience (e.g., emotional experience) in this group. Although I do not disagree with Barron and Klein (1) that comparative neurobiological studies will help us understand the evolution of neural mechanisms for a wide variety of abilities, I am not sure that I would look to the insects to learn about the evolution of consciousness. The constraints on the size of insect nervous systems (6) may preclude its development in this group.

Therefore, Barron and Klein's conclusion that insects are conscious (1) is surprising, only because the word "conscious" carries certain connotations. Stripped of the term "consciousness," their conclusions are not controversial. For example, a bee without the ability to "simulate the state of the animal's own mobile body within the environment" would be incapable of foraging and navigation. What is surprising is not that bees can form neural simulations of their environment, but the labeling of this ability as consciousness.

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# Avoid the hard problem: Employment of mental simulation for prediction is already a crucial step

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Barron and Klein (1) highlight the importance of a simulation-based account of planning ahead as a central mechanism to allow for basic cognitive properties. They relate this on a functional level to a detailed architecture of central circuits in the human midbrain. As a major contribution, they further compare these structures with functionally similar ones in the insect brain. They assume that central to both structures is an integrating and predictive model of the body, including aspects of the environment. Therefore, they conclude that the ability to plan ahead, using such a body model for internal simulation, is not unique to humans or vertebrates, but is a more general and older principle already present in some invertebrates, particularly insects.

They further relate the concept of internal simulation to the notion of consciousness, and particularly to subjective experience. From our point of view, mental simulation and relating oneself to the environment are certainly requirements for phenomenal consciousness. However, it is not shown in any way that these capabilities necessarily lead to subjective experience. Therefore, in our view, the article is not contributing to the discussion of subjective experience. Instead of trying to argue on this slippery ground, we propose to leave aside completely the question concerning subjective experience, which Chalmers characterizes as “the hard problem” (2). Instead, we should focus on a description on the functional level, which allows us, following Cleeremans (3), to divide consciousness into access consciousness and reflexive consciousness. Importantly, this approach matches well with the functional view of Barron and Klein (1) without the need to use the concept of subjective experience.

Following such an approach provides a functional and testable account of parts of consciousness. Here, we agree that this can already be found in quite simple systems. Modeling approaches can be used to test for such emergent properties. As one example, we modeled an insect-based approach for walking that reflects, on a detailed level, behavioral and, to some extent, neurophysiological findings, including action selection on different levels of the reactive system (4). When this approach was extended to include a functional model of the body in relation to the environment, the system was shown to allow for planning ahead (5) and, as we argued in detail, fulfilled the basic conditions required for access consciousness (3). In this way, such an insect-based model constitutes a functional description for access consciousness without the need of discussing the concept of subjective experience, but it is still well in agreement with the core mechanism described by Barron and Klein (1). Our computational approach (5), which is currently being implemented on a physical robot to validate these hypotheses, shows that one requirement is the ability to decouple the body model from the motor output. Secondly, the model has to be manipulable. Even though these requirements only introduce small changes into the insect-based systems, they have, to date, not been shown in insects. Correspondingly, a central “metric place” is not required to describe the navigation behavior known from central-place foragers (ref. 5 and references therein).

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REPLY TO ADAMO, KEY ET AL., AND SCHILLING AND CRUSE:

# Crawling around the hard problem of consciousness

Colin Klein<sup>a,1</sup> and Andrew B. Barron<sup>b,1,2</sup>

One goal of our paper (1) was to invite constructive empirical debate. We are glad that several authors have taken up this invitation.

Two letters (2, 3) claim that our characterization of subjective experience was too liberal. Adamo (3) misreads us. We do not simply define subjective experience as a type of integrated information processing. Rather, such processing is the mechanism that makes a first-person, phenomenally rich perspective on the world possible.

Schilling and Cruse (2) think we are wrong to set aside access consciousness. They are here and elsewhere (4) committed to the thesis that subjective experience requires access consciousness. This claim is philosophically contentious, even in humans (5), and one that we deny. Broadly speaking, we claim that insects are aware of the world (including the state of the mobile body within the world), and that this awareness feels a certain way to the organism that has it. The stronger thesis, which they endorse, says that awareness is always awareness of one's own mental states. We think that their thesis is less economical, faces harder philosophical challenges, and biases investigation against simple animals. We thus prefer representational models that are "self-interpreting" (6), rather than requiring an extra layer of processing.

Key et al. (7) doubt the vertebrate midbrain supports the capacity for subjective experience. Our case relied on a diverse set of evidence from lesion and anesthesia studies (not just the case of anencephalic infants), although we acknowledged that this localization is far from settled. They also support their claim by reference to work on the supposed absence of pain in fish. That work is itself highly controversial (8), and makes several assumptions about the physiology of pain and cortical contribution to pain that we would deny.

For example, Key (9) emphasizes the role of somatosensory and insular cortex in the human experience of pain. However, lesions of somatosensory cortex disturb only localization of pain (10). More serious insular damage disturbs the motivational force of pain (so-called "pain asymbolia"), but that is only because such damage disturbs the experience of bodily

ownership more generally (11). The subjective experiences of any animal, including any experience of pain, will be appropriate to its body and its form of life.

Key et al. (7) also note that cortical damage changes what we are aware of, and that visual cortex damage appears to eliminate conscious vision. One should not confuse the experience of a human with a damaged visual cortex with the experience of an animal that never evolved a cortex in the first place, however. As the Sprague effect (12) illustrates, proper functioning of midbrain visual structures depends on a balance of inhibitory inputs from both the cortex and other midbrain structures.

More generally, in our article, we were careful to distinguish between the contents of subjective experience and the basic capacity to have any experiences at all. Our argument exclusively concerned the latter. More complex animals are capable of more complex experiences. The cortex surely plays an important role in enriching the contents of human experience. It is thus no surprise that damage to (say) the visual cortex would lead to corresponding impoverishments of visual experience.

Adamo (3) proposes that insects have too few neurons in the brain to support subjective experience. We refute this proposition. The insect brain can support the key functions of the vertebrate midbrain, even though far fewer neurons are devoted to a given function in an insect than in vertebrates. For example, we agree with Adamo (3) that insects do not process emotions in the same way vertebrates do; whereas larger vertebrates devote entire nuclei to the processing of "emotional" states, insects support processing of motivational functions with clusters of just a few neurons (13–15). These clusters are specialized circuits that regulate and convey information on vital internal states (arousal, satiation, hunger, and reward) to systems processing sensory information and supporting memory (13–15). As we have argued, this system is sufficient to support a basic subjective experience of the world. This point illustrates the economy of scale of the insect brain, and also demonstrates how the functional organization of the system is a far more important consideration than neuron number, as has been argued elsewhere (16).

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We agree with Schilling and Cruse (2) on the benefits of functional definitions of conscious phenomena. We also agree that a central metric space is not required to support central space foraging. We have not proposed that the only way to navigate or process position and spatial relations is by a “cognitive map”. There are many ways to represent spatial relations and functions in the brain, as insect studies have shown (17).

Finally, Schilling and Cruse (2) note that we do not attempt to solve the so-called “hard problem” of consciousness (18). Adamo’s response (3) similarly suggests that an explanatory gap remains. We agree. We have presented evidence about the structures that support conscious experience, and the functional properties of those structures that seem to be important. However, we have not tried to explain how the personal feeling of a mental process could arise from a lump of neurons. Our investigation is very much in the spirit of Penfield and Rasmussen, who urged that

“...neurologists should push their investigations into the neurologic mechanism associated with consciousness and should inquire closely into the localization of that mechanism without apology and without undertaking responsibility for the theory of consciousness” (19).

That said, we think that Schilling and Cruse are fellow travelers in this regard. As they have argued elsewhere (4), the current state of consciousness research resembles the study of “vital forces” in the 18th century. Then too, there seemed like a great gap between the organic and the inorganic. This problem was dissolved, not solved, by the subsequent development of appropriate scientific concepts for understanding life.

We consider our work to be very much in the same vein. The hard problem is hard not because it has no answer, but because we do not yet know what a satisfying answer could look like. It is the job of philosophy to keep alive such questions (20). It is the job of neuroscience to forge ahead regardless, and to do its best to outflank mysteries that cannot presently be tackled head-on.

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