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REVIEWS

Letter

Experiment Rather Than Define

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Taiz *et al.* contend that 'plants neither possess nor require consciousness' [1]. Their essay is the most recent contribution to a long-running series of disputes about whether the concepts and reasoning strategies of psychology can be extended to plants. At the root of their essay is a weakness that pervades these disputes. They exaggerate the role of definitions.

Taiz *et al.* focus on some claims made by Monica Gagliano. Gagliano and her colleagues claim to have good evidence that garden peas (*Pisum sativum*) learn by association: they claim that peas learn to associate the direction of a breeze with the direction of a light, learning which is displayed when the peas grow towards the breeze in the absence of light [2]. Such learning has not previously been demonstrated in plants, thus Taiz *et al.* reasonably raise questions about important aspects of the experimental design of Gagliano *et al.* They put those questions aside to focus on the further claim by Gagliano that these results suggest that plants are conscious [3]. They say that she has gone too far, and the concept of consciousness should not be applied to plants. They claim that Feinberg and Mallatt have identified what types of anatomy and physiology are required for consciousness [4]. In contrast to Gagliano, Taiz *et al.* contend that plants are not conscious because plant anatomy and physiology do not fulfill the requirements as laid out by Feinberg and Mallatt.

Although the work of Feinberg and Mallatt improves our understanding of some important matters, it does not show that plants are not conscious. Instead, their work simply assumes that plants are not conscious. They survey only animals on the assumption that no other organisms have consciousness. Thus, by relying on their work, Taiz *et al.* beg the question of whether plants are conscious.

The main weakness in the essay by Taiz *et al.* is that they think that focusing on the definition of consciousness will help to settle the issue of whether the concept of consciousness can be extended to plants. In doing so, they assume that our concept of consciousness is sufficiently general to account for all possibilities, and that when we grasp it properly we will see clearly what it rules in and rules out. However, there is no good reason to accept this assumption [5]. Consider, for instance, the definition of 'phenomenal consciousness' on which Feinberg and Mallatt (and thus Taiz *et al.*) rely. It comes from Antti Revonsuo [6]: 'The mere occurrence or presence of any experience is the necessary and minimally sufficient condition for phenomenal consciousness. For any entity to possess primary phenomenal consciousness only requires that there are at least *some* patterns – any patterns at all – of subjective experience *present-for-it*. It is purely about the *having* of *any* sorts of patterns of subjective experience, whether simple or complex, faint or vivid, meaningful or meaningless, fleeting or lingering' (emphasis in the original [6]). Let us grant that we have some antecedent grasp of what it is for us humans to have something present-for-us. What would it be for a plant to have something present-for-it? This definition does not tell us. Would it not be the same sort of thing that it is for us? Perhaps, but that still leaves us wondering what counts as 'the same sort of thing'. Moreover, simply thinking rigorously about that definition is not going to reveal this – there is no good reason to think that how we ought to move from the case of humans to the case of plants is simply bottled up within the definition. Maintaining otherwise requires assuming our antecedent grasp of something present-for-us somehow anticipated the possibility of something present-for-plants and decided on that possibility.

This weakness is not unique to the essay by Taiz *et al.* It pervades disputes about whether we should extend the concepts and reasoning strategies of psychology to plants. It arises when discussing important allied concepts such as the concepts of intelligence, cognition, and mind [7]. It occurs whenever someone thinks that these disputes should fundamentally focus on definitions or concepts. We should be careful and explicit about how we use words, but that is a start to fruitful discussion, not the end of it.

Although we cannot settle whether plants are conscious simply by scrutinizing the definition of consciousness, we do not need to proceed in that way. Instead let 'the productivity of research programs guide the extension of language to new contexts' [8]. What does this mean? We discover whether the concept of consciousness can be fruitfully applied to plants by trying to apply it to them, and then assessing the weaknesses and strengths of those efforts. This includes the type of experiments that Gagliano *et al.* have conducted, as well as the refinements suggested by Taiz *et al.* It might go on to include other types of associative learning cataloged by psychologists [9]. Through an extended series of this type, experimentalists might learn that there is a fitting successor to the concept of consciousness (or phenomenal consciousness) that works well for plants. It would thus be part of a collection of concepts of consciousness that have been discovered over many decades of inquiry [10].

Should we extend our strategies for reasoning about the behavior of animals to reasoning about the behavior of plants? That is best addressed not by peering more carefully into our definitions but by figuring out in practice how well those strategies extend to plants, and what types of modifications are and are not

effective in probing the behavior of plants. In a slogan, we should experiment rather than define.

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Letter

Physiology and the (Neuro)biology of Plant Behavior: A Farewell to Arms

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Sterile arguments over the definition of plant intelligence or consciousness do not advance understanding, instead they hinder it. Cooperation, rather than controversy, and 'an end to arms' is the way forward.

About four centuries ago, Van Helmont concluded that plants grew by taking up water rather than eating soil, as the Inquisition insisted. But that simple experiment ushered in plant physiology as a scientific discipline, leading, in the 19th century, to the first genuine text on plant physiology by Sachs [1]. Although both zoologists and botanists use the word physiology, surely no-one doubts that the functioning of green plants is very different to that of the common animal.

Controversies over behavior, intelligence, and consciousness are not new but are part of a long botanical tradition [2]. Attempts at rigid definitions are usually not helpful and commonly defeated by scientific progress [3]. Biologists continue to research living organisms without any agreed definition of life [4]. Why should 'intelligence', 'consciousness', or 'cognition' be any different?

The opinion article of Taiz *et al*. [5] provides a mixture that reflects the orthodox, 'pure'(?), physiology attitude. While Taiz *et al*. [5] are clear that plants are not like animals, an animal-centric definition of consciousness is used to insist that plants do not have or need it. This is surely circular reasoning. One way or another, other misunderstandings and construction of straw man arguments abound. This letter is a short note of warning with regard to some of the mis-directions.

A number of quotes from the article of Taiz *et al*. serve to illustrate the tendentious reading made of the research carried out within the field of Plant Neurobiology [6]. Notably, '…the group quietly changed its name…'. But, probably, the following extract serves to illustrate where the misunderstanding resides and, more importantly, what the plant science community needs to bear in mind to avoid witnessing sterile disputes. Consider for the sake of illustration the following: 'Time-lapse videos of growing roots or twining stems, which have been speeded up to make them look more animal-like, do not constitute evidence for consciousness or intentionality.' The interpretation of Taiz *et al.* is symptomatic of a widely spread misunderstanding. Intelligence and consciousness are not specific to the type of responses that happen to be closer to our scale of observation. Paradoxically, a zoo-centric attitude appears behind their charge of zoo-centrism.

It is not a question of whether time-lapse data can or cannot constitute evidence of plant consciousness. In our view, it is plainly obvious that it cannot and we have never defended this [7]. What is symptomatic is the characterization of the usage of time-lapse footage as if meant to make plants 'look more animal-like'.

But why would the use of time-lapse techniques amount to anthropomorphizing plant research? Time-lapse is used in a variety of disciplines, not to make their objects of study 'look more animal-like', but simply to reveal complex patterns that would be missed otherwise; in the case of the plant sciences, to reveal, for instance, patterns of behavior that would otherwise be deemed rigid and inflexible [8,9].

In this respect, time-lapse is not unlike Darwin's recording of plants' movements of nutation using glass plates [10], or by infrared radiation, used in the middle of the last century [11]. Either of these techniques allows researchers to collect a number of parameters (period, length, rate, shape, etc. [12]), helping determine kinematic and dynamic aspects of plant movement, including velocities and accelerations. In themselves, they do not fall prey of biases by default; anthropomorphism is rather in the eye of the beholder.

One way or another, plant behavior can take many forms other than the structuring of flexible patterns of growth and development as identified under time-lapse readouts [8,9]. Other more direct or indirect