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ARTICLE

# Biomimetic Epistemology

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## Abstract

Imitating nature is an ever more popular strategy in many fields of science and engineering research, from ecological engineering to artificial intelligence. But while biomimetics and related fields have recently attracted increased attention from philosophers, there has been relatively little engagement with what I suggest we see as their basic epistemological presupposition: that we may acquire knowledge from nature. I argue that emphasizing and exploring this presupposition opens up a new approach to epistemology, based on a shift from a conventional epistemological relationship to nature as object of knowledge to a biomimetic relationship to nature as source of knowledge.

## 1. Introduction

Various fields of research focus explicitly on imitating nature, namely, biomimetics, biomimicry, bioinspiration, and bionics (Vincent et al. 2006; Hoeller et al. 2013). Many fields also, at least on some theorizations, take the idea of imitating nature as a basic principle or premise, including agroforestry (Young 2017), artificial neural networks (Krogh 2008), ecological design (Todd and Todd [1984] 1993), evolutionary computing (Foster 2001), industrial ecology (Lowe and Evans 1995), and regenerative agriculture (Gremmen 2022). Last, several fields may plausibly be seen as very often involving the imitation of nature—even if it is not always recognized or emphasized—including artificial intelligence (Bar-Cohen 2006), the circular economy (MacArthur 2013), and synthetic biology (Bensaude-Vincent 2009). Imitating or drawing inspiration from nature, we may conclude, is an increasingly important feature of contemporary science and technology.

Thus far, the epistemological issues raised by biomimetics and related approaches have received relatively little attention (Drack and Jansen 2022). Imitating or drawing inspiration from nature has been much discussed, including in the philosophical literature (e.g., Bensaude-Vincent 2011; Blok and Gremmen 2016; Gerola et al. 2023; Mathews 2011; Tamborini 2023), but the specifically epistemological issue of learning from nature, that is, in some sense acquiring knowledge from nature, has received only occasional philosophical attention (e.g., Krohs 2021; Dicks 2023). As for scientific publications, this epistemological dimension is often present in the titles of articles—for example, "Biomimetics: Lessons from Nature—an Overview" (Bhushan 2009), "Chemists and the School of Nature" (Bensaude-Vincent et al. 2002), "Learning from Nature—Biomimicry Innovation to Support Infrastructure Sustainability and Resilience" (Hayes et al. 2020)—but without being explicitly analyzed in the articles themselves. That there is much we may learn from nature would thus appear to be an epistemological presupposition of the field, rather than an issue that the field itself has sought directly or explicitly to address. The starting point of this article is that this epistemological presupposition not only merits serious philosophical analysis but may give rise to an entirely new approach to epistemology, the key feature of which is its emphasis on learning from nature: biomimetic epistemology.

Before I begin setting out this approach, let me briefly say something about the distinction between what we might call "fields" of epistemology, on one hand, and "approaches" to epistemology, on the other. By a field of epistemology, I mean a domain of inquiry to which epistemological analyses may be applied. These often, but not always, go by the name of "epistemologies of . . . " Epistemology of science, epistemology of technology, and moral epistemology are familiar examples. By an approach to epistemology, I mean a way of thinking about or understanding knowledge. These are typically described by the "-ism" through which questions relating to knowledge are approached. Examples include empiricist, naturalist, and feminist epistemologies. That fields and approaches are quite different is visible in the fact that different approaches may be applied to different fields, as in, say, feminist epistemology of science (Haraway 1988).

The reason this distinction is relevant in that it brings our attention to a possible distinction between epistemology of biomimetics (a field) and biomimetic epistemology (an approach). The work of Krohs (2021) is an example of the former. It takes a specific domain of research—biomimetics—and then seeks to analyze some of its epistemological aspects. My aim in this article is somewhat different, and closer in this respect to my own previous research (Dicks 2017, 2019b, 2023): it is to develop a new approach to epistemology, a new way of thinking about knowledge. The main difference from my previous research is that my aim here is not so much to offer anything like a fully fledged theory of biomimetic epistemology, as I attempted to do in *The Biomimicry Revolution* (Dicks 2023, 198–249), but rather to focus on *justifying* the approach in the first place, through setting out and defending what I take to be its two key premises.

But let us first consider briefly what is distinctive about biomimetic epistemology. Many approaches to epistemology make general claims regarding the origin and nature of knowledge. Empiricist epistemology, for example, typically claims that all knowledge comes ultimately from the senses and internalist epistemology that all knowledge comes from internal cognitive faculties and mental states. Other approaches seek, rather, to counter such claims. A rationalist does not claim that all knowledge comes from reason but rather that not all knowledge comes from the senses (for reason is an important source too), and an externalist does not typically claim that all knowledge comes from external sources but only that the sources of knowledge are not all internal. Biomimetic epistemology is better seen as making an epistemological claim of this second sort: it does not claim that all knowledge comes from nature; rather, it takes issue with what it sees as the dominant view in epistemology—that all knowledge comes in one way or another from humans, whether through their cognitive or epistemic faculties (the senses, reason, introspection, or memory) or via other humans (notably in the form of testimony). Biomimetic epistemology may thus come to be recognized as a new approach to epistemology, the distinctive feature of which is the emphasis it places on nature—especially nonsentient nature—as a source of knowledge.

## 2. Premises of biomimetic epistemology

### *2.1 Premise 1: Nature is not only something we may learn about but also something we may learn from*

It seems reasonable to say that the conventional epistemological relation to nature involves seeing nature as something we may learn about, as an object of knowledge. Naturalist epistemology (Quine [1969] 2000) may partially challenge this inasmuch as, by naturalizing the human knower, it also sees nature as the subject of knowledge (i.e., as the knower and not just the known), but the relation between subject and object remains conventional: a (naturalized) subject acquires knowledge about a natural object. In biomimetic epistemology, by contrast, nature is seen quite differently, as something we may learn from—as a source of knowledge, not an object of knowledge (Benyus 1997, 9; Dicks 2023, 201).

A simple example may bear out this distinction. Whereas a conventional epistemological relation to nature may involve, say, learning about photosynthesis in plants, a biomimetic epistemological relation would involve learning from plant photosynthesis how we might go about developing "artificial photosynthesis" (Kalyanasundaram and Graetzel 2010).

Nevertheless, despite both the intuitive appeal of this distinction and its obvious practical relevance, it seems fair to say that it has yet to receive much in the way of sustained attention either from epistemologists or from philosophers of science and technology.

### *2.2 Premise 2: Knowledge is generated in and by nature*

This second premise is implicit in the first. If we may learn from nature, then knowledge must first have been generated—in some form or other—in and by nature, assuming it not to have been put there by something supernatural. Combined with the first premise, an important implication is that not all our knowledge comes from humans, whether through our own cognitive faculties—the senses, reason, introspection, and memory—or from other humans, as in the case of testimony. To say that knowledge is generated in and by nature and that we may learn from that knowledge is thus to add another source of knowledge—learning from nature—to the exclusively human ones recognized in conventional epistemology (Audi 1998).

It could be objected here that the conventional assumption that testimony is the sole way in which we acquire knowledge from others is simply a result of the fact that the type of knowledge with which epistemologists have been most concerned is knowing that (propositional knowledge), as opposed to knowing how or knowing by acquaintance. Indeed, it does not seem particularly insightful or original to say that nonpropositional knowledge, especially knowing how, may be acquired from others, most obviously by watching and imitating what they are doing (Fridland and Moore

2014; Fridland 2018). Nevertheless, the other from which knowing how is acquired is typically assumed to be another human. All Ryle's (1946) examples of knowing how, for example, relate to sorts of knowing how learned at least in part from other humans: playing chess, riding a bike, making good jokes, and so on. Where biomimetic epistemology innovates, then, is in its focus on nonhumans—or humans conceived as natural entities open to scientific observation—as sources of knowledge. We may, for example, learn from the lotus plant how to make self-cleaning surfaces (Karthick and Maheshwari 2008), from mangroves how to desalinate water more sustainably (McKeag 2023), or from the human brain how to perform various forms of computation (Iliadis et al. 2020).

The claim that knowledge is generated by and present in nature, including in plants and the body parts of animals (humans included), is, however, much more controversial than the claim that other humans generate forms of knowing how that we may acquire through watching and imitating them, for it requires us to adopt a view of knowledge as potentially nonsubjective, that is, as potentially present in nonsentient entities. If we may learn from plants how to develop artificial forms of photosynthesis, it is not through watching a nonhuman subject perform the act of photosynthesis and then copying that act, for there is no reason to think of plants as conscious subjects aware they are photosynthesizing. Nevertheless, if we are to learn from them, they must be seen as embodying knowledge, in this instance, knowledge of how to photosynthesize.

## 3. Justifying biomimetic epistemology

The premises of biomimetic epistemology are independent of their justifications to the extent that, in theory at least, it might be possible to justify them in various ways. Nevertheless, if we are to take these premises seriously, we must at least have an idea of why one might be prepared to accept them. In what follows, I will thus explore what I take to be some of the most promising strategies of justification.

### *3.1 Justifying premise 2: Knowledge is generated in and by nature*

I shall start with premise 2, as it logically precedes premise 1. It is because knowledge is generated in and by nature (premise 2) that, in addition to learning about nature, we may also learn from nature (premise 1). The key objection from which I will seek to defend this second premise is an obvious one: there is no knowledge in nature, or at least in nonsentient nature, for knowledge requires a knower, that is to say, some sort of conscious subject who is, as it were, doing the knowing.

With a view to responding to this objection, let us first try to ascertain what type of knowledge biomimetic epistemology thinks is acquired from nature. Traditional epistemology recognizes three types of knowledge: knowing that, knowing by acquaintance, and knowing how. Of these, it seems reasonable to say that the main—perhaps even the only—type of knowledge we may acquire from nature is knowing how. Even if it were true that some natural beings, such as higher animals, possess knowing that, it is far from clear how they might transfer that knowledge to us in the absence of propositional language. As for knowing by acquaintance, though it is more plausible to view this as existing in at least some nonhuman natural entities, it would not appear to be the sort of knowledge that can be transferred at all. I may, for example, learn certain things about another person by what someone else tells me about them, but this is very different from being acquainted with that person myself. This would appear to leave only knowing how, and indeed, it is common for researchers in biomimetics and related fields to talk about the many things we may learn from nature how to do. The chapter titles of Benyus's (1997) *Biomimicry*, for example, almost all take the form "how will we . . . ?"—with imitating and learning from nature supplying the answers.

A key question the biomimetic epistemologist must answer, then, is this: can the claim that knowing how is generated in and by nature be justified? One way they might seek to answer this question affirmatively would be by drawing an analogy with technology. Consider cameras. It is certainly not unreasonable to say that cameras embody knowledge of how to record visual images, and yet this is not to say that the knowledge in question is known by the camera. Something analogous, the biomimetic epistemologist might contend, is true of nonsentient nature. Eyes, for example, embody knowledge of how to record visual images, but this is not to say that this knowledge is possessed either by the eyes themselves or by any knowing subject to whom they might belong, for that subject may have no idea how it is that their own eyes work.

The critic or skeptic could make two plausible objections to this analogy. First, they could argue that there is a difference between the two cases, for in the case of a technological object, the knowledge it contains was previously present in the mind of a conscious subject, and, assuming living beings to be products of evolution as opposed to intelligent design, the same is not true of them. In short, they could defend the following position: we may say that an item of knowledge, K, is embedded in an object, O, without being known by O, if and only if it was previously known by a conscious subject, S, who thereafter embedded it in O.

The second objection draws on vehicle externalism (Rowlands 2003). According to vehicle externalists, the mind is not limited to what goes on inside the head, for it extends outside the head into the external world. Technologies are not just objects into which knowledge has been externalized, for the human mind extends outside the body and into these objects. Furthermore, one might even think that the presence of knowing how in technological objects constitutes an argument for vehicle externalism, for how else can we account for the knowledge present in these external objects? If all knowledge has a knower and there is knowledge embedded in technology, then this can only be because that knowledge belongs to a mind that *extends* to technology. In the case of nonsentient nature, however, no mind is present at all, and so no knowledge either.

Whichever of these two objections one puts forward, an interesting consequence is that, when two entities, one biological, the other technological, are functionally identical in some respect, only the technological one can be said to embody knowledge. For example, both heliotropism in plants and human-made solar-tracking systems have the function of maximizing exposure to sunlight, but if the current objection is true, only the latter embody knowledge, for the ability of plants to track the sun is neither something they know how to do nor the result of knowing how being externalized.

Rather than attempting a direct response to these objections, let us first consider another way the biomimetic epistemologist might try to justify the claim that knowing how is generated in and by nonsentient nature: by analogy with certain forms of knowing how in humans. In some instances, human knowing how calls for full and undivided attention. Professional tennis players competing in grand slam tiebreaks are likely to be concentrating hard on playing tennis. But there are other things humans know how to do so well that they may perform them while thinking about something else, that is, "absent-mindedly." An experienced driver may be deep in thought about something and so not actually aware that they are driving. They may only become aware that they are driving when the car in front brakes sharply and they suddenly "come to their senses." Likewise, it is often the case that certain parts of a task are performed without conscious awareness. Someone experienced in writing with a computer keyboard may be focused entirely on the content of what they are writing, paying no attention at all to the action—which one could hardly doubt that they know how to perform—of pressing buttons in the required order with their fingers.

It would seem, then, that there is a case for saying that that which we know best how to do is that which does not require conscious awareness. A beginner tennis player may need to use their full and undivided attention just to hit the ball over the net, whereas an expert player may know how to play so well that they are able to conduct a lengthy rally simply by "going through the motions" and so potentially when their consciousness awareness is directed to something else. But if humans may potentially know how to do things nonconsciously, and may even demonstrate the very highest levels of knowing how when doing things nonconsciously, then the claim that knowing how requires a conscious knower becomes doubtful, and it becomes plausible to maintain that knowing how is present in nature even in the absence of a conscious knower.

This is likely to meet with an analogous counterargument to the one made with respect to the analogy with technology. The nonconscious knowing how exhibited by experienced human subjects—tennis players, drivers, keyboard writers, and so on—differs from putative instances of knowing how in nonsentient nature, for it was consciously acquired, as all knowing how must be.

As in the case of the analogy with technology, two slightly different objections might be formulated here. First, it could be objected that, just as knowing how may be externalized in the form of technologies, in the case of nonconscious or ingrained knowing how, a different form of externalization occurs—not from inside the head to the external world but from our internal minds to our external bodies. In nonsentient nature, however, no such externalization from mind to body is possible.

The second objection draws once again on the notion of the extended mind, except that the claim here is not that the mind extends outside the head into the external world but rather that it extends outside consciousness into other parts of the self, such as nonconscious parts of the brain, the nervous system, and even other bodily organs. Nonconscious or ingrained knowing how would thus be knowing how that had been externalized from the conscious to the nonconscious mind. In nonsentient nature, however, no such externalization from the conscious to the nonconscious mind can occur, and in that case, one cannot speak of knowing how in nature.

This second objection does, however, open the door to another argument the biomimetic epistemologist may wish to put forward. If there is no simple Cartesian divide between the conscious mind and the material or extended body, for mind or cognition can be present in nonconscious forms in the body, then it follows that knowing how may be present in nonconscious and embodied forms without having arrived there through externalization from consciousness.

An example of this way of thinking about the mind is Humberto Maturana and Fransisco Varela's (1980) theory of biological cognition, according to which cognition is fundamentally embodied and occurs in all living beings, even nonsentient ones. When one further considers their view that cognizing and knowing are inseparable, that living is not merely a cognitive process but also an epistemic one (Maturana and Varela 1980, 119; 1987, 25–26), this theory clearly has the potential to justify the view that knowledge is present even in nonsentient organisms. Furthermore, given that Maturana and Varela see cognizing and knowing as connected fundamentally to the maintenance of autopoiesis, it would seem that at least some of the forms of knowing involved in the process of living would best be characterized as "knowing how," for what they ultimately embody is nonconscious knowledge of how to maintain autopoiesis. If a plant, for example, is able to sense sunlight and then orient itself toward it, for sunlight provides the energy the plant requires to "produce itself," then the plant can be said to know how to orient itself toward the sun, even though this knowing is not conscious.

An interesting consequence of this argument is that it makes it possible to turn the tables on the preceding objection that knowledge is present only in technological entities, not in biological ones. Indeed, from the perspective of Maturana and Varela's theory of embodied cognition, knowledge would be present in heliotropic plants but not in artificial solar-tracking devices, at least unless the latter were seen as belonging to the extended minds of humans. Solar-tracking devices do not cognize in ways that help maintain their autopoiesis, for as technological objects, they do not produce themselves but are instead produced by humans.

Unlike in the case of plants, there is thus no "self"—produced by the very process of "self-production"—that may be said to be performing the cognizing or knowing.

One important objection that could plausibly be raised here is that any knowing how present in a living organism would concern only its behavior—what it does, not the various functional anatomical traits of which it is physically composed. Consider an analogy with technology. A photographer may know how to use a camera, and yet the knowing how embodied in the camera itself, that is, the technical knowledge it embodies of how to record images, may be unknown to the photographer. By the same token, a living being may know, even if only nonconsciously, how to use its bodily organs to achieve an effect, but without possessing the knowing how the biomimetic epistemologist claims is embodied in the organs themselves. An insect, for example, may know how to fly, for this involves biological cognition, but this is not to say that the putative knowing how embodied in its wings—relating to their aerodynamic form, lightweight material, and so on—is possessed by the insect.

An even clearer example—and one of well-known relevance to biomimetics—concerns the hydrophobic surfaces of the lotus plant. These surfaces are not smooth, as one might expect, but instead exhibit microscopic bumps that prevent water droplets from sticking to the plant's leaves, and the droplets thus roll off, taking dirt particles with them. Here, then, we have a functional trait that would not appear to involve biological cognition. The droplets simply roll off, as they do in the case of biomimetic reproductions of lotus leaves, without any biological cognition being involved. The lotus plant may be cognizing in other respects (Calvo 2016), for example, as regards the detection of sunlight and nutrients or in making "decisions" related to root growth (Lee et al. 2023), but the lotus effect from which humans allegedly learn does not involve any cognition and so cannot embody any knowing how. If this objection were valid, it would greatly reduce the scope of biomimetic epistemology, for a great many functional biological traits of interest to human designers would not actually embody any knowing how.

In response to this objection, the biomimetic epistemologist may question the analogy with technology. It is not the case that the functional anatomical traits of living organisms are *first* produced and *only thereafter* used by organisms. Indeed, whereas a camera is first produced in a factory and only later used by a photographer, in the case of living beings, any functional anatomical traits they possess (eyes, wings, etc.) are produced *by the living being itself* in the course of its self-production. And if living, as Maturana and Varela claim, is a cognitive process, and if every living being produces itself, its various functional anatomic traits included, then it would seem to follow that biological cognition is involved also in producing these functional anatomical traits. From this perspective, it is the organism itself that generates the knowing how embodied in its functional anatomical traits, something it achieves by converting genetic information into phenotypic knowledge via processes involving biological cognition. Ontogenetic and physiological processes, from this perspective, are triggered or modulated by processes involving cognition at molecular and other levels, including, to give a key example, the way gene transcription is regulated by activator and repressor proteins—a form of biological cognition at the molecular level.

The critic or skeptic could nevertheless maintain that many of the functions embedded in the anatomical traits of living organisms are not things that the organism itself knows how to do, for the performance of the function does not involve any cognition, as in the preceding example of the hydrophobic surface of the lotus plant. Cognitive processes occurring within the organism may be involved in *generating* the traits responsible for these functions, but this is not to say that it is the organism itself that knows how to *perform* the functions themselves, for, at least in some cases, no cognition is involved. The biomimetic epistemologist is thus faced with the following problem: they claim that knowledge is embodied in the functional anatomical traits of organisms, and yet this knowledge is not known by the organism itself, in which case, not only do we have knowledge without a conscious knower but, even more problematically, we appear to have knowledge without any knower whatsoever.

This raises the following question: is it possible to demonstrate the presence of knowing how in the functional anatomical traits of living organisms even when no cognition is involved? Leaving aside the complex debate about what exactly function is (e.g., Cummins 1975; Boorse 1976, 1977; Millikan 1989; Neander 1991), I will in what follows attempt to justify two key claims: (1) that every functional anatomical trait in nature embodies knowledge of how to achieve that function and (2) that the true bearer of this knowledge is not the individual organism but rather the species.

With these objectives in mind, let us first take a detour via mainstream discussions of knowledge. Knowledge, and more specifically propositional knowledge, has traditionally been defined as justified true belief (JTB). The JTB theory of knowledge was, however, famously criticized by Gettier (1963), who provided various counterexamples in which what someone believed was true and they were justified in believing it, but they nevertheless lacked knowledge. This then sparked various attempts to replace, modify, or improve upon the JTB theory of knowledge. Reliabilism, for example, contends that a true belief counts as knowledge only if it has been formed using a reliable process.

Contemporary debates about knowing how are for the most part quite different. In keeping with the central importance accorded to propositional knowledge in contemporary epistemology, the question that is most often addressed is the relation between knowing how and knowing that, in particular whether knowing how can be reduced to knowing that, or vice versa (Stanley and Williamson 2001; Pavese 2022). It is also possible, however, to ask analogous questions of knowing how to those asked with respect to knowing that. One may, in other words, ask when it is that someone can really be said to know how to do something.

An obvious possibility here would be to require that person to demonstrate their knowing how by performing the corresponding action. The main problem here is that, as in so-called Gettier cases, "epistemic luck" may be involved. Just as someone may get lucky when pointing at the one true barn among a series of mere facades and then claiming to "know" it's a barn, so someone may perform a task by fluke, without really knowing how to do it (Williams 2008). Someone may, for example, hit the bull's-eye when playing darts for the first time through sheer "beginner's luck." Furthermore, even if that person were to hit the bull's-eye several times in a row, this would not prove conclusively that they know how to hit the bull's-eye, for, while statistically improbable, pure fluke could theoretically account also for their performing this feat several times in a row.

So, when does someone know how to do something? The diversity of ways in which philosophers have sought to answer the question of when someone can be said to possess propositional knowledge suggests that there may be several different theoretical options here. Let us focus, then, on just one plausible contender: reliabilism. Just as reliabilists maintain that someone possesses knowing that when that knowledge has been produced via a reliable process, so the same principle could be applied to knowing how. Someone knows how to do something when their demonstrated ability to do it is the result of a reliable process. So, what reliable processes are there for generating knowing how? These may, of course, vary depending on the type of knowing how involved, but, at the risk of overgeneralizing, plausible answers clearly involve things like practice, training, and education. If someone had spent several years playing darts in a club, competing in regular tournaments, and so on, then we may reasonably assume that their demonstrated ability to hit the bull's-eye (regularly, if not every time) was a genuine skill—something they knew how to do and not a fluke.

The preceding analysis makes it possible to affirm a clear analogy between knowing that and knowing how. Adopting a reliabilist perspective, we may say that someone knows that something is the case when (1) they believe it, (2) that belief is true, and (3) that belief was produced by a reliable process. By analogy, we may say that someone knows how to do something when (1) they are able to do it, (2) that ability is demonstrable, and (3) that ability was produced by a reliable process. Knowing how, we may infer, exists wherever there is a *reliably produced demonstrable ability*.

Given this characterization of knowing how, let us now turn our attention to the question of whether knowing how is embodied in the functional anatomical traits of living beings. If knowing how were present in the functional anatomical traits of living beings, these traits would need to exhibit demonstrable abilities produced by a reliable process. The hydrophobic surfaces of lotus plants, for example, would need to be able to repel water in such a way that dirt particles are carried away, that ability would need to be demonstrable, and it would need to be produced by a reliable process.

I claim that the functional anatomical traits of organisms satisfy all three of these criteria. The ability to repel water is clearly present in the functional anatomical traits of lotus plants, namely, their hydrophobic surfaces, and it is also clearly demonstrable, for it has been confirmed by scientific observation. But can we say that this demonstrable ability was produced by a reliable process? The fundamental process responsible for generating functional anatomical traits in living beings, the hydrophobic surfaces of lotus plants included, is natural selection. And there can be little doubt that natural selection is a reliable process for generating knowing how; not only has it given rise to vast quantities of demonstrable abilities throughout the living world but the very process of selection means that traits from which knowing how is either absent or present only insufficiently or inadequately will tend to be eliminated. Lotus plants that are not able to repel water droplets, or that do so less effectively than other plants, will, all other things being equal, tend to be eliminated.

To some extent, moreover, the reasons natural selection is a reliable process for generating knowing how are analogous to those concerning the generation of knowing how by human practice: both involve trial and error, selecting what works, and building on past successes. Likewise, it is also worth noting that, just as there exist various ways in which the knowledge generated in and by humans—whether knowing that or knowing how—is both preserved and handed down to future generations, such as imitation, language, and education (Fridland 2018), the same is true also of the knowledge generated in and by nature, even if the mechanisms in question—DNA replication, mitosis, DNA repair, and so on—are quite different.

Let us now turn our attention to the question of who or what is the bearer of this knowledge. There is, I believe, no nonmetaphorical sense in which lotus plants can be said to know how to keep themselves clean by repelling water from their leaves. But this is not to say that lotus plants are not "bearers" of this knowledge, in a comparable way to how human technologies may be "bearers" of knowledge, without themselves knowing the knowledge, for in both cases, reliably produced demonstrable abilities are present.

Furthermore, there are two reasons I believe it makes more sense to see the bearers of the knowledge embodied in functional anatomical traits as the species, rather than the individual organism. First, the knowing how in question will be present in every member of the species in which the corresponding trait is normally present,[1] provided, of course, that the trait is functioning correctly. It matters not which individual specimen of the species *nelumbo nucifera* we observe with a view to

[1] The reason I say "normally present" is that not every functional anatomical trait would normally be present in every member of the species. It is perfectly normal for certain functional anatomical traits not to be present in juveniles, in one or the other of males or females, or in specific castes. Only members of the reproductive caste of leaf-cutter ants, for example, possess wings.

learning how to achieve the lotus effect artificially. Second, it is at the level of the species that the knowledge is generated, for it arises through the differential survival of organisms better able to perform the function in question. So, whereas humans (and other organisms) may get better at performing certain actions through practice, the same is not true with respect to the sort of functional anatomical traits under discussion (i.e., those whose performance does not involve cognition at the level of the individual organism).[2] It is not through practice that the leaves of lotus plants have gotten better at repelling water but through natural selection acting on random genetic mutations—a process that can be understood only at the level of the species, not at the level of the individual.

In view of these considerations, the biomimetic epistemologist must clearly reject the claim that knowledge always requires a conscious knower. They would even reject the idea that all knowledge requires a knower, understood here as a cognitive agent, even a nonconscious one. But they would affirm that knowledge requires a bearer, be it the organism or the species, in which that knowledge is embedded, even if only in nonconscious and sometimes also noncognitive form.

### 3.2 Justifying premise 1: Nature is not only something we may learn about but also something we may learn from

Biomimetic epistemology does not claim only that knowledge is generated in and by nature but also that it is possible for that knowledge to be acquired by humans. This, then, is what the biomimetic epistemologist means when they say that we may "learn from nature." The key objection from which I will seek to defend this premise is the following: no knowledge is acquired from nature during the process of biomimetic innovation, for any knowledge that humans thereby come to possess is generated by their own cognitive faculties and may thus be explained by conventional epistemology.

The obvious challenge the conventional epistemologist faces in affirming that we do not learn anything from nature is to explain why it is so often said that we do. The most likely way they would answer this challenge would be by saying that when scientists and engineers talk of "learning from nature," "lessons from nature," the "school of nature," and so on, they are not expressing literal truths at all but anthropomorphic metaphors. Metaphors drawn from the conventional context of social epistemology—humans learning from other humans—are being used to talk about the epistemological relationship between humans and nature, even though humans do not, literally speaking, learn anything from nature.

It is important to realize that the conventional epistemologist's objection here could potentially take two forms. First, the claim could be that, because we do not learn anything from nature, when someone says that we do, this can only be meaningfully interpreted as a metaphor. If whoever uses such language thinks they are expressing a literal truth, they are mistaken; it is a *dead* metaphor, one that has become so familiar that they fail to realize that it is not literally true. Second, the claim could be that when scientists and engineers talk of "learning from nature" and the like, they know full well that they are speaking metaphorically. In support of this

[2] Traits that perform their function through hard-wired cognition, without any learning involved, are an in-between case, analogous to the innate propositional knowledge postulated by rationalists, for the knowing how in question belongs to both the individual and the species.

latter claim, the conventional epistemologist might argue that, if expressions such as "learning from nature" and "lessons from nature" are usually found in the titles of articles, this is not because they embody an epistemological presupposition but rather because titles afford opportunities to use precisely the sort of colorful metaphorical language that would be out of place in the article itself, which must stick to literal truths.

The difference between these two claims is important. It is widely recognized that it is an error, especially in philosophy of science, to try to align philosophical interpretations of key words and expressions (e.g., the word *function* in biology) with ordinary language use (Amundson and Lauder 1994, 445–46), but for philosophical analyses not to be aligned with how the scientists themselves understand and talk about their field is more problematic. If the scientists and engineers working in biomimetics and related fields think that we do not actually learn anything from nature, then biomimetic epistemology may face an uphill challenge. If, on the other hand, they consider that there is knowledge embodied in nature that we may acquire, it is rather the conventional epistemologist who would find themselves in an awkward position.

It would make an interesting topic for experimental philosophy to seek answers to this question by means of surveys, questionnaires, and the like. My personal experience suggests that those working in the field are somewhat unsure about and divided over this issue and that women are typically more open to the idea that we may learn from nature than are men, but, in the absence of any solid empirical data, I shall address only the first claim: that it is simply not possible to learn anything from nature, in which case, any statement to the contrary can only meaningfully be interpreted as a metaphor.

How might the biomimetic epistemologist respond? The obvious strategy would be to say that, although human cognitive faculties are certainly involved in learning from nature, their role is not to generate knowledge from scratch but to act as a conduit or channel through which knowledge initially generated in and by nature is acquired. They may then point to an analogy with testimony. To gain knowledge from the testimony of someone else typically involves the senses (e.g., hearing in the case of oral testimony), along with reason, such that we may follow any logical connections involved, and various forms of memory. But this is not to say that any knowledge acquired through testimony is being generated as opposed to received.

The conventional epistemologist could, of course, reply that testimony is very different from alleged instances of learning from nature, for not only is the type of knowledge different but, more importantly, testimony is possible only when knowledge is present first in a knowing subject, whereas in most cases of biomimicry, we are not learning from nature qua knowing subject at all. This is true, but the simple existence of a difference does not prove that knowledge cannot first be present in nature and then acquired by human subjects. It may simply be that learning from nature is an additional source of knowledge—one that resembles testimony in that it involves learning from others but that differs in other respects, namely, from who or what we learn, the ontological status of the knowledge involved, and how it is transferred.

So, who is right? If the conventional epistemologist were right, biomimetic innovation would be but an application of a conventional epistemological relationship to nature. Biomimetic innovation, from this perspective, would first involve obtaining knowledge *about* nature via conventional scientific study, and that knowledge would then be applied in ways that mimic the natural system in question, thereby generating knowing how not actually present in the natural system itself. If, on the other hand, biomimetic innovation involves a new epistemological relationship to nature based on obtaining knowledge *from* nature, it would be the biomimetic epistemologist who was right.

With a view to resolving this issue, let us begin by noting that science—the preeminent way in which we obtain knowledge about nature—often involves modeling nature. Given this, the conventional epistemologist would likely want to argue that biomimetics also involves modeling nature and that it differs from conventional science only in the way these models are developed and applied. We may model a leaf differently if our aim is to contribute to the advancement of plant physiology from how we would model it if our aim were to develop a new technique for artificial photosynthesis, but this variability is true of all modeling. We develop different models for different purposes. Water, for example, may be modeled as a set of molecules in some contexts and as a flowing liquid in others (Giere 2004, 749–50). Scientific modeling for purposes of biomimicry is no different; it involves first developing models of natural systems—a form of learning about nature—and then applying those models in mimetic ways.

How might a biomimetic epistemologist respond? They could start by noting that the language used in biomimetics and related approaches is quite different. In conventional science, we typically speak of "modeling" or "developing models of" natural systems. In biomimetics, by contrast, we speak rather of "abstracting models from" natural systems (International Organization for Standardization [ISO] 2015; Dicks 2023, 245). The conventional epistemologist may at this point be tempted to retort that all models are abstractions, for they only ever reflect certain features or aspects of the observed system. The different linguistic expressions used, they might infer, do not reflect any substantial difference in meaning. But this would be to miss an important point that may not be immediately visible in the linguistic expressions themselves, namely, a crucial ambiguity in the word *model*. One of the most significant differences between conventional and biomimetic epistemology is the way they characteristically understand the word *model*. In conventional epistemology, a model is a representation of something; it is the imitation of the thing. In biomimetic epistemology, by contrast, the model is not a representation but a blueprint or template; it is the thing to be imitated, not the imitation of the thing (Dicks 2023, 235–36). To say, then, that all models are abstractions is beside the point, for we are talking in one case about models in the sense of representations and in the other about models in the sense of templates.

This is not to say that models developed with a view to representing nature, to learning about nature, cannot be used for purposes of biomimetic innovation. When one starts from an engineering problem and then peruses conventional scientific publications to see if there is anything in nature that may have solved this problem already, this is precisely what is taking place. But this is not to say that biomimetic epistemology is but an application of conventional epistemology. The first reason is that even just to describe nature as having "solved problems" is already an epistemic characterization; even if nature is at this point only something we learn about, it is still often conceptualized as a bearer of knowledge.

The second reason is that the model developed must undergo an important ontological shift that is easily obscured by the polysemic nature of the word *model*: the model in the sense of a representation (learning about nature) must become a model in the sense of a template or blueprint (learning from nature). Whatever knowledge we acquire about nature, it follows, is not simply applied but transformed; no longer an instance of knowledge about nature, it becomes a medium through which knowledge is acquired from nature.

The third reason is that it is also possible that no ontological shift occurs whatsoever, that we do not first model nature and then apply that model—transformed in the meantime from a representation to a template—to biomimetic innovation; rather, we directly abstract models—in the sense of templates or blueprints—from nature. Indeed, this is precisely how the process of biomimetic innovation is standardly described (ISO 2015). First, we observe a natural system; then we abstract a model from that system; then we transfer that model over to a target artificial system. If biomimetic epistemology only ever began with a conventional epistemological relationship to nature, the process would presumably be described quite differently. First, we would observe a natural system; then we would develop a model of that system; then we would take that model (qua representation) as a model (qua template) for another system; then we would transfer that model (qua template) over to the target system. But the fact that this is not how the process is standardly described implies that the underlying epistemological framework of biomimetics is not conventional; what occurs in biomimetic innovation is not simply the application of knowledge about nature but rather the abstraction of knowledge from nature and its transfer to a target system.

Another quite different argument the conventional epistemologist may wish to make would involve accepting that knowledge is generated in and by nature, but then rejecting the possibility that it may be acquired by humans. Consider again the case of testimony. If a scientist were to tell someone with no knowledge of chemistry that water is $H_2O$, and if that person had no good reason to doubt the truth of what the scientist were saying, we may infer that they have acquired knowledge of the chemical composition of water. In the case of biomimetics and related fields, however, knowledge is rarely straightforwardly transferred. As Vincent et al. (2006, 474) put it, "a simple and direct replica of the biological prototype is rarely successful, even if it is possible with current technology. Some form or procedure of interpretation or translation from biology to technology is required." The objection, then, is that we cannot speak of knowledge as transferred from nature, because the knowledge in question will assume a significantly different form when realized in an artificial system, in which case, it is not the same knowledge at all. What is happening, in other words, is not that knowledge is being transferred but rather that one item of knowledge is providing the inspiration for the generation of a *different* item of knowledge. In such a scenario, all the knowledge we humans possess would still be generated by our own cognitive faculties.

One way to resolve the disagreement in favor of the biomimetic epistemologist would be by reference to the concept of abstraction. Imagine that someone hears from a scientist that water is $H_2O$ but then states that what they learned was that water is a molecule. This is clearly not what the scientist said, but it is not implausible to maintain that this more abstract item of knowledge was acquired from the scientist via inferential reasoning. After all, prior to having heard from the scientist, the person might have thought that water was an atomic element, and so, for them, the most salient thing learned was not water's chemical composition but rather that it has a chemical composition. Similarly, as long as some item of knowing how—no matter how abstract—is acquired from nature, we may reasonably speak of knowledge transfer. Inferential reasoning may be required for the knowledge to acquire the more abstract form in which it may be employed by humans, but nature would remain its original source.

Blok (2023) provides a useful formalization for thinking about this. What he calls "strict imitation" is formalized as $A = A$. An example is the total synthesis of the naturally occurring molecule Paclitaxel, which is used in anticancer drugs. What he calls "biomimicry," which he thinks always involves some sort of "translation," is formalized as $A \rightarrow A^1$. An example would be the Shinkansen 500 series, a high-speed Japanese train that reproduces the form of the beak of the kingfisher almost identically, while also introducing various modifications required by the new context, such as an enlarged scale and different materials. And last, what Blok calls "nature-inspired invention" is formalized as $A \rightarrow B$. The example he gives is the Eastgate Centre in Harare, which, though inspired by the way termite mounds keep cool in high temperatures, turned out to be based on a misunderstanding and so ultimately achieves the cooling effect quite differently.[3]

In view of this, what the biomimetic epistemologist can maintain is simply that, as long as some item of knowledge—no matter how abstract—is transferred from the natural to the artificial system, it is a genuine case of biomimicry ($A \rightarrow A^1$). Of course, one may also sometimes encounter instances of "nature-inspired invention" ($A \rightarrow B$), in which the observation of a natural system inspires the invention of an artificial system without any transfer of even the more abstract forms of knowing how present in the natural system; but, contrary to the view of the conventional epistemologist, this is not the only possible scenario, for biomimicry ($A \rightarrow A^1$) may also—and often does—occur.

A final consideration that may favor the position of the biomimetic epistemologist concerns the alleged disanalogy with testimony. The idea that testimony involves the straightforward transfer of knowledge could itself be questioned on the grounds that knowledge must always be assimilated and, in being so, will inevitably undergo processes of selection, interpretation, and articulation that mean it is not quite the same knowledge as it was in the mind of the person offering the testimony. Even a scientific testimony to the effect that "water is $H_2O$" could potentially be understood in different ways, especially when we consider that a single molecule of $H_2O$ "doesn't have any of the observable properties we associate with water" and that any observable body of even very pure water "is better understood as containing $H_2O$, $OH^-$, and $H_3O^+$" (VandeWall 2007, 910). But if knowledge often undergoes modifications when transferred from one human to another in testimony, then, unless we are willing also to reject testimony as a source of knowledge, the fact that knowledge often undergoes modifications when transferred from nature to humans is not a reason to reject biomimetic epistemology.

[3] This is not to say that all nature-inspired invention is based on misunderstanding. If the architects of the Eastgate Centre had studied termite mounds and then knowingly implemented a different way of achieving the cooling effect, it would also count as "nature-inspired invention."

## 4. Conclusion

Of the two premises of biomimetic epistemology, the second is the most important. If we can establish that knowledge is present in nonsentient nature (premise 2), then the idea that we may acquire knowledge from nature (premise 1) is likely to be accepted. The conventional epistemologist may, of course, still try to insist, as a point of principle, that there is no knowledge without a conscious knower, and so no knowledge in nonsentient nature. But, even under this scenario, I would hope that the arguments presented herein—especially the argument that knowing how, conceptualized as reliably produced demonstrable ability, is present in embodied forms in the functional anatomical traits of nonsentient organisms—would at least convince the conventional epistemologist to recognize biomimetic epistemology as a worthy adversary, as a new approach to epistemology that is at least worth taking seriously.

By way of conclusion, I will now consider another reason for taking biomimetic epistemology seriously, namely, its theoretical and practical significance, before suggesting some further important research questions not directly addressed in the present article.

What ultimately sets different approaches to epistemology apart is the source of knowledge they emphasize: the senses (empiricist), reason (rationalist), introspection (Cartesian), memory (Platonic), naturalized cognition (naturalist), other humans (social), external factors (externalist), gender and situatedness (feminist), and so on. The most obvious way in which biomimetic epistemology is theoretically significant, then, is that it not only introduces a new source of knowledge, nature (especially nonsentient nature), but also makes us aware of a trait common to all the conventional approaches to epistemology listed earlier: their belief that what ultimately generate knowledge are the cognitive faculties of humans (and perhaps other sentient animals).

Also of theoretical significance is the way biomimetic epistemology challenges the very concept of knowledge. There can be little doubt that human propositional knowledge remains the paradigmatic type of knowledge dealt with in epistemology. Even discussions of human knowing how for the most part still revolve around whether knowing how is reducible to knowing that (Pavese 2022). But, as soon as one accepts that every single one of the countless species of living beings on earth possesses copious amounts of nonconscious knowing how embodied in their myriad physiological traits, the central importance and paradigmatic status that epistemologists typically attribute to conscious propositional knowledge in humans become highly questionable. Such knowledge comes to appear as something rare and exceptional, an evolutionary outlier, rather than as the paradigm for knowledge in general.

In breaking with these two key beliefs of conventional epistemology—that all knowledge is generated by human cognitive faculties and that the paradigmatic form of knowledge is conscious knowing that—biomimetic epistemology breaks also with what is arguably its most basic theoretical feature: anthropocentrism. A parallel with environmental ethics is revealing. This branch of ethics is often traced back to Leopold (1949), who, rejecting the view that we have moral duties and responsibilities only to other humans, proposed an expansion of the boundaries of the moral community such that it would henceforth include various nonhuman others.

Three-quarters of a century later, the idea that the moral community includes nonhumans is now, if not universally accepted, at least seriously debated. Moreover, it is interesting to note that the principal stumbling block to the two main forms of nonanthropocentric environmental ethics, biocentrism and ecocentrism, is the same as that faced by biomimetic epistemology: it is debatable whether an entity that lacks sentience—whether an organism or an ecosystem—can possess moral standing, just as it is debatable whether a nonsentient entity can possess epistemic standing. Epistemology, by contrast, has not undergone a parallel shift. The epistemic community it theorizes remains composed solely of humans and at most also a select few higher animals. In keeping with this, the concept of epistemic standing is typically applied only to humans (Gressis 2021), with the rest of nature being characterized by its absolute ignorance.

Of course, in expanding the boundaries of the epistemic community, we must avoid indiscriminate anthropomorphism. Just as environmental ethicists recognize all sorts of differences and asymmetries between human and nonhuman members of the enlarged moral community (Taylor 1986), something analogous would hold of the enlarged epistemic community theorized by biomimetic epistemology. It may well be, for example, that only humans possess propositional knowledge; that only humans and some higher animals possess conscious knowing how; and that, whereas humans can learn from nonsentient nature, the reverse is not true.

But the conventional alternative of restricting the epistemic community solely to humans must also be avoided. Indeed, if conventional epistemology is correct, then, even in apparent instances of biomimetic innovation, we are not actually learning anything from nature but engaging instead in the generation of entirely new items of knowledge. Biomimicry, understood as the translation of an item of knowledge embodied in nature into the realm of human design ($A \rightarrow A^1$), is not even considered possible; the only real possibility is for new items of knowledge to be "invented" by humans, taking nature as a source of inspiration ($A \rightarrow B$). The central biomimetic idea that we may "learn from nature" is thus treated as a metaphor, and "nature-inspired invention" becomes the only appropriate way to characterize what takes place in biomimetics and related fields.

From this steadfastly anthropocentric perspective, no knowledge was present anywhere on earth until humans arrived, and any knowledge we may come to possess could only ever be generated by our own cognitive faculties. Biomimetic epistemology, by contrast, proposes a quite different view—a view of nature as having generated vast quantities of knowledge over the course of billions of years of evolution, with humans arriving late on the scene with much to learn from the multitudinous other life-forms that have, in many cases, been present on earth for much longer than we have (Benyus 1997). This, in turn, implies a significant rethinking of our understanding of epistemic virtue, which would lie less in dispositions conducive to generating new items of knowledge and more in dispositions conducive to acquiring existing knowledge from nature, such as respect and admiration for all that nature has already learned how to do, openness to what nature may teach us, and wonder at how the knowledge present in nature gets articulated into complex systems (Dicks 2023, 190–94).

Biomimetic epistemology is also of great practical significance. An ever-increasing amount of research and development involves learning from nature, and, especially when one factors in the scope of learning from nature how to do things in ways that are much more environmentally sustainable (Benyus 1997), the idea that we may be in the early stages of a Biomimicry Revolution comparable in scope and significance to the Industrial Revolution (Benyus 1997, 2), and perhaps even to the Enlightenment (Dicks 2023, 250–56), is not implausible. That philosophers emphasize and explore the specifically epistemological aspects of this revolution is important for at least two reasons: first, it may influence how learning from nature is put into practice and thus how the revolution—if indeed it is one—will unfold, and second, it may allow biomimetics and biomimicry to be taken more seriously, to be discussed more widely, and to be explored and implemented more thoroughly. If they are no longer seen as just quirky and unorthodox approaches to engineering and design, but rather as manifesting a profound epistemological shift in the way we think about and relate to nature, the likelihood that they will profoundly change the world—ideally in ways that embody the wisdom to which true philosophy aspires—may increase accordingly.

As regards the content of such engagement, the present article leaves many questions at least partially unanswered, three of which strike me as particularly important. First, who or what are the bearers of knowledge in nature? If I have concentrated on organisms and species, this does not mean that knowledge does not belong to other biological or ecological entities, most obviously animal or insect societies and/or ecosystems. Any such knowledge would also need to be theorized, conceptualized, and justified, drawing on relevant literature in the philosophy of biology and ecology.

Second, is it true that the only type of knowledge we may acquire from nature is knowing how? Much of the existing philosophical literature on biomimicry considers the possibility that we may derive some sort of "ecological ethics" from nature (Blok and Gremmen 2016; Dicks 2019a, 2023). Could it be, then, that we may learn from nature not only how to do things but also what it is that we ought to be doing?

Third, how exactly does biomimetic epistemology relate to other approaches to epistemology? I have already mentioned externalism and naturalism, but other approaches merit further analysis too (Dicks 2023, 201–14). To give just one example, could biomimetic epistemology be theorized as but an expanded form of social epistemology, one that includes nonhumans? Biomimetic epistemology's relation to non-Western epistemology is also of great interest. Mathews (2011) has already explored the relation between biomimicry and Daoism, and there is certainly scope for pursuing this exploration from an epistemological perspective. Likewise, the frequently observed proximity between the biomimetic idea of "learning from nature" and indigenous epistemologies (Benyus 1997; Kimmerer, 2013) warrants further reflection. Taken together, these research possibilities raise the tantalizing possibility that the development of biomimetic epistemology may open the door not only to a revolution in Western epistemology but also to its unification with Eastern and indigenous epistemologies. Perhaps it is the expansion of the epistemic community to include nature that holds the key to bringing the human epistemic community closer together.

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