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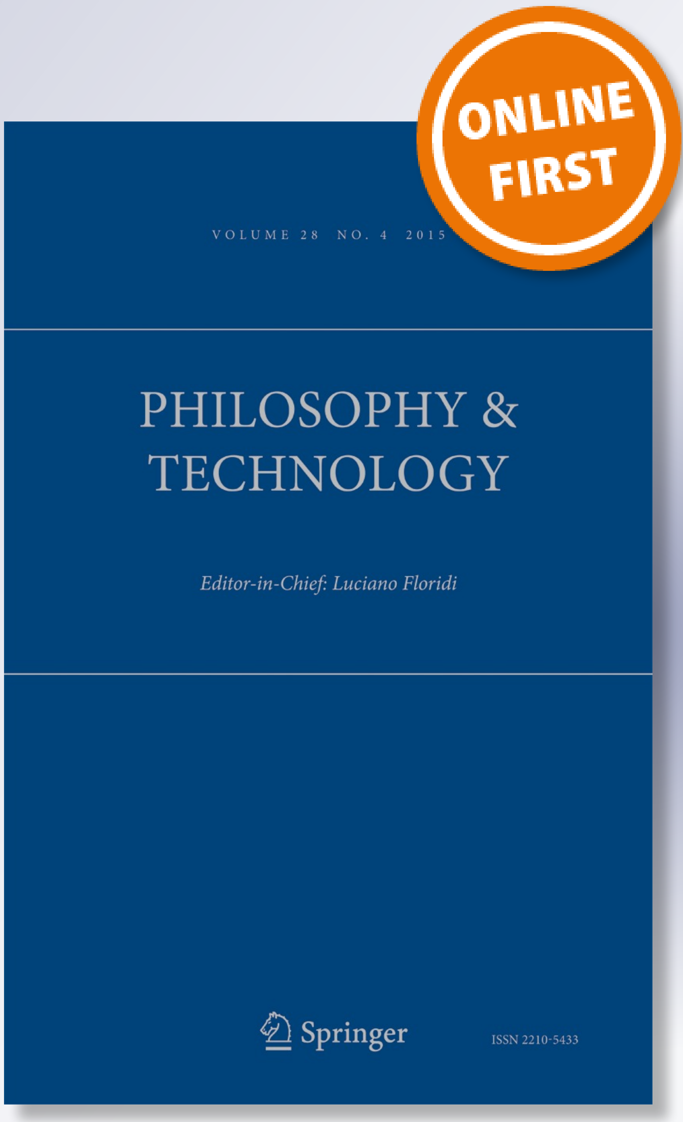

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RESEARCH ARTICLE

The Philosophy of Biomimicry

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Abstract The philosophy of biomimicry, I argue, consists of four main areas of inquiry. The first, which has already been explored by Freya Mathews (2011), concerns the "deep" question of what Nature ultimately is. The second, third, and fourth areas correspond to the three basic principles of biomimicry as laid out by Janine Benyus (1997). "Nature as model" is the *poetic principle* of biomimicry, for it tells us how it is that things are to be "brought forth" (*poiēsis*). "Nature as measure" is the *ethical principle* of biomimicry, for it tells us that Nature places ethical limits or standards on what it is possible for us to accomplish. And "Nature as mentor" is the *epistemological principle* of biomimicry, for it affirms that Nature is the ultimate source of truth, wisdom, and freedom from error. Within this overall framework, I argue that seeing Nature as *physis*—understood as "self-production" or "self-placing-into-the-open"—constitutes the requisite ground for the poetic, ethical, and epistemological principles of biomimicry, and that biomimicry thus conceived involves a new philosophical paradigm, which I call "enlightened naturalism".

Keywords Autopoiesis · Physis · Mimesis · Bio-inspiration · Bio-design · Enlightened naturalism

1 Introduction

There can be little doubt that the recent surge of interest in biomimicry[1] is heavily indebted to Janine Benyus's *Biomimicry: Innovation inspired by Nature* (Benyus 1997). Indeed, one could perhaps even consider Benyus a "founder of discourse" in Foucault's sense, for the basic principles she spells out at the beginning of *Biomimicry* would appear to have produced not only what Foucault calls "the possibilities and rules

[1]See Lepora et al. (2013) for an attempt to quantify this "surge of interest" within scientific publications.

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for the formation of other texts" but also "a possibility for something other than their discourse, yet something belonging to what they founded" (Foucault 1979, 154), and in particular, those discourses that set themselves up in partial opposition to biomimicry and which go under such names as "bio-inspiration" (e.g. Forbes 2005) and "bio-design" (e.g. Myers 2014). In this respect, Benyus could be said to stand in a comparable relation to biomimicry as Freud does to psychoanalysis or Marx to Marxism.

The comparison with Freud and Marx does, however, also reveal a significant difference between the discourses they founded and biomimicry. Whereas the fields of discourse opened up by Marx and Freud contain substantial and extensive philosophical reflections on their own foundations, the same cannot really be said of biomimicry, which, as Freya Mathews has rightly noted, is "philosophically under-developed, descriptive, and ad hoc" (Mathews 2011, 4). There are two obvious reasons one might put forward to explain this. First, biomimicry typically brings together scientists focusing on practical applications, exponents of various different "technological" disciplines (engineering, architecture, design, agronomy, robotics, computing, etc.), as well as business people, the result being that the functional and economic viability of biomimetic products generally takes priority over philosophical questioning. Second, *Biomimicry* is not only the work of someone with little or no academic background in philosophy but also to a large extent adopts the discursive hallmarks of popular science—an informal and journalistic style, a focus on concrete examples, etc.—and, as such, implicitly sees its principal task as popularizing the underlying techno-scientific research and development from which it draws its examples, rather than working out a comprehensive philosophical framework.

Despite all this, a brief consideration of the three principles Benyus lays out at the very beginning of her book—Nature as model, Nature as measure, and Nature as mentor—suffices to give a preliminary understanding of biomimicry's distinctive philosophical status, for, as we will see, they involve a way of thinking that is radically distinct from the three main philosophical paradigms that have characterized Western thought since the ancient Greeks—medieval Christianity, modern humanism, and postmodern relativism—which attribute the role of model, measure, and mentor, respectively to God, to man, and to beings.

According to Christianity, which dominated Western thinking during the Middle Ages, humans are created in the *image* of God and God's love and beneficence are also a *model* for human action. Likewise, Christians believe God to be the *measure* of human actions, judging them against His own absolute knowledge of right and wrong, while at the same time acting as humanity's *mentor*, an epistemological guide to turn to for truth, knowledge, and freedom from error.

Later, as medieval Christianity gives way to modern humanism, an ideal essence of man—as free, rational, equal, etc.—becomes the model which real humans and their institutions strive to imitate. Similarly, it is man, or perhaps rather man's distinctive and essential properties, which becomes the measure of the rightness and wrongness of human actions and institutions. According to Kant (1988), for example, an action is right if and only if it is carried out in conformity with the uniquely human faculty of reason. And man also becomes his own mentor, as humans look first to themselves—a turn whose methodological basis lies in the Cartesian *cogito*—in their epistemological quest for truth, knowledge, and freedom from error.

As for postmodern relativism, it may be seen as the culmination of the progressive breakdown of the abstract ideal of man characteristic of modern humanism, a process that played itself out over the course of the nineteenth and twentieth centuries. Marxism initiated the idea of humanity as riven by economic and class divisions. Psychoanalysis revealed hitherto overlooked conflicts and tensions between the free, rational, and conscious subject of traditional humanism and the drives and impulses of the unconscious. Feminism and queer studies emphasized the philosophical importance of questions of gender and sexuality. Anthropology and ethnology drew attention to the ethnocentrism of Western humanism. And animal rights and ecological activism highlighted its inherent anthropocentrism. This overall process of "post-modernisation" may be seen as culminating in the work of Bruno Latour, who views the world as a vast actor-network comprising human and non-human entities, every single one of which is in theory capable of becoming a model, measure, and mentor for any other, hence his "principle of relativity", according to which all entities may become models for other entities via processes of translation (Latour 2011, 248–249), his explicit view that "everything is the measure of everything else" (Latour 2011, 243, my translation), and his claim that epistemological pretentions to know "the truth" are ultimately just "trials of strength" between different entities or alliances of entities within the actor-network (Latour 2011, 323).

Set in this broad and schematic historical context, the biomimetic view of Nature as model, measure, and mentor would appear to propose a radical turn in Western thought towards a certain kind of naturalism. The nature of this naturalism will, however, necessarily remain obscure as long as we see the basic philosophical contribution of biomimicry as reducible to the three principles of Nature as model, measure, and mentor. Indeed, these principles only directly tell us about certain key aspects of *the human relationship to Nature*; they do not directly tell us *what Nature is*. It is for this reason, then, that in the opening and most explicitly theoretical chapter of *Biomimicry*, Benyus sets out a second set of nine statements, explaining what she takes to be Nature's "laws, strategies, and principles":

Nature runs on sunlight.

Nature uses only the energy it needs.

Nature fits form to function.

Nature recycles everything.

Nature rewards cooperation.

Nature banks on diversity.

Nature demands local expertise.

Nature curbs excesses from within.

Nature taps the power of limits. (Benyus 1997, 7)

An important task for the philosophy of biomimicry is clearly to analyse these statements as regards their meaning, truth, coherence, comprehensiveness, and so on. Likewise, it is also important to analyse the differences between "laws", "strategies", and "principles" and then to apply this analysis to the various statements in question. It is clear, for instance, that "laws" are very different from "strategies", for whereas a law is either something that is always followed or something whose transgression will be penalized, a strategy is rather a course of action that it may prove advantageous to adopt. To take a simple example, it is clearly not the case that Nature always "runs on sunlight" or that organisms will necessarily be penalized if they do not do so. Certain deep sea organisms, for example, depend on hydrothermal vents to produce organic material via chemosynthesis.[2] So, even when indirect use of solar energy (wind, hydro, biomass) is factored in, the claim that "Nature runs on sunlight" is clearly not a *law*, though this is not to say that it is not the *principal strategy* for energy procurement adopted by life on earth.

Given the scale and complexity of these tasks, let us for the time being note simply that without some sort of characterization of Nature biomimicry would be radically incomplete and ill-defined, for we cannot take something as model, measure, and mentor without some sort of understanding of what it is. Moreover, this is particularly true when the thing in question is "Nature", for the meaning of the word—and even the viability of using it at all—is highly controversial and contested (Latour 1999; Morton 2009). But, while Benyus's nine statements do at least give some idea of what she means when she speaks of "Nature", they remain philosophically inadequate. Simply listing a variety of different *ways in which Nature works* leaves open the question of what *Nature ultimately is*. The nine "laws, strategies, and principles" Benyus outlines may *point towards* what Nature is, for, to the extent that they are true statements about how Nature works, Nature must be something which does indeed work in those ways, but that still leaves unresolved the deeper question of the "nature of Nature". As Freya Mathews has argued: "Observations such as that 'nature runs on sunlight', for instance, and that nature 'banks on diversity', are handy rules of thumb for designers, but in no way render nature intelligible to us—they do not fit together into an intelligible order" (Mathews 2011, 8).

In view of these general considerations, the present article is structured as follows. In the first part, I take up and rework Mathews' project of developing a "deeper philosophy of biomimicry". My key argument here is that biomimicry will ultimately have to come to depend on an explicit understanding of Nature as *physis*, and that physis must in turn be understood as autopoiesis or self-production. This view of Nature as physis constitutes what I call the "ontological principle" of biomimicry, for, as I show via a reading of Edgar Morin (and later on Martin Heidegger), it leads to the view that Nature qua physis is "Being itself". In parts two, three, and four, I then turn my attention to the three key dimensions of the human relationship to Nature characteristic of biomimicry: (i) Nature as model, which I call the "poetic principle" of biomimicry, for it is concerned with the "production" or "bringing forth" (*poiēsis*) of things; (ii) Nature as measure, which I call the "ethical principle" of biomimicry, for it is concerned with the limits and standards against which the "rightness" of our actions may be judged;

[2] Interestingly, it is certainly not out of the question to imitate or draw inspiration from these organisms so as to generate energy and capture valuable materials from hydrothermal vents.

and (iii) Nature as mentor, which I call the "epistemological principle" of biomimicry, for it is concerned with Nature as a source of truth, knowledge, and wisdom. The overall schema of the philosophy of biomimicry—and thus also of the present article—may thus be represented as follows:

	Nature as *Physis* (*Ontological principle*)	
↙	↓	↘
Nature as Model (*Poetic principle*)	Nature as Measure (*Ethical principle*)	Nature as Mentor (*Epistemological principle*)

2 Nature as Physis

The contemporary literature on biomimicry consists to a large extent of successful or promising examples of biomimetic design (e.g. Fournier 2011). Nature, in this context, assumes the form of a sort of repository, inventory, or catalogue of potential "design solutions". This view of Nature is further encouraged by websites set up to promote biomimicry, such as *asknature.org*, whose search engine invites us to complete the question "How does Nature…?" in ways of our choosing. One obvious problem here is that reducing Nature to an inventory or database of "design solutions" involves an understanding of Nature that lacks any sort of structure, hierarchy, or means of distinguishing the essential from the inessential. As noted above, it is to counter this problem that Benyus has put forward a "canon of laws, strategies, and principles", which detail what she considers to be the fundamental or essential ways in which Nature works. In a similar vein, Julian Vincent et al. (2006) have argued that the problem-solving system, TRIZ, may reveal a "common set of principles" governing the workings of Nature and capable of "regularizing" the transfer of function from biology to engineering. But whatever the set of principles one settles upon, the same fundamental question would still apply: what is Nature such that it works in accordance with them?

As already noted, Freya Mathews is well aware of the limitations of Benyus's understanding of Nature, hence her characterization of the nine principles, strategies, and laws Benyus outlines as "descriptive but not explanatory" (Mathews 2011, 8). In response to this, Mathews proposes two fundamental principles she considers distinctive of Nature: the "principle of conativity" and the "principle of least resistance". She explains the first of these as follows:

> It asserts that all living beings and living systems are animated by a will or impulse to maintain and increase their own existence. In contemporary systems theory this will-to-self-actualization is usually referred to as autopoiesis, but I prefer the term conatus or conativity, as it has a longer philosophical lineage and is not confined to the terms of reference of any particular branch of science, such as systems theory. (Mathews 2011, 8)

The second principle depends on the first, inasmuch as it proposes that living beings and systems realize their "will to existence" by adopting what she calls the "path of least resistance" (Mathews 2011, 9). In what follows, I follow Mathews in arguing that understanding Nature as autopoiesis does indeed constitute an appropriate ground for biomimicry. Likewise, I also follow Mathews in expanding the scope of the concept of autopoieisis beyond that proposed by its original theorists, Humberto Maturana and Francisco Varela, such that the concept also applies to various entities that are not strictly biological, and in particular, stars, vortices, and ecosystems. My position differs from hers, however, in two key respects. First, I do not equate autopoiesis with the notion of a "will to existence" or "conatus", a notion also present in Mathews' earlier work, *The Ecological Self*, where she claims that living organisms and other analogous systems, such as vortices, are "self-realizing" and that self-realization involves the coincidence of purpose with existence (Mathews 1991, 102). My position, by contrast, agrees rather with Maturana and Varela's view regarding the "dispensability of teleonomy" (Maturana and Varela 1980, 85–87), that is to say, the view that the attribution of purposes or goals to living beings implies a projection onto living beings of concepts that derive from the sphere of human design (heteropoiesis). Living beings bring themselves into existence, but "willing" is not intrinsic to that process any more than it is intrinsic to the self-production of stars, vortices, or ecosystems.[3] The second way in which my argument differs from that of Mathews follows on from the first: since I do not equate autopoiesis with the notion of a "will to existence", there is no reason to assume that autopoietic entities realize their "will" by adopting the "path of least resistance".[4]

According to Maturana and Varela (1980), an autopoietic being possesses two key properties. First, its various parts produce each other in a recursive manner. This property is, however, shared with autocatalytic reactions, hence what they consider the second key property of autopoietic beings: the production of a boundary or closure which delimits the living being as a unity while at the same time participating recursively in the production of its other components. Autopoiesis, it follows, stands in close proximity to Stuart Kauffman's theory of life as "autocatalytic closure" (Kauffman 1995). Where Kauffman goes beyond Maturana and Varela, however, is in his detailed argument that it was through the achievement of autocatalytic closure that life first came into existence. In opposition to the dominant view of life as emerging from a prior process of molecular self-replication, Kauffman argues that life first emerged "complex and whole" in the form of closed, autocatalytic networks. So, whereas biologists like Richard Dawkins (1989) or the theorists of RNA world believe that life was *produced by something other than itself that existed before it* (self-replicating macromolecules, the ancestors of genes), Kauffman holds that life *produced itself* thanks to the achievement of autocatalytic closure. This, then, is what he means when he states: "With autocatalytic sets, there is no separation between genotype and phenotype. The system serves as its own genome" (Kauffman 1995, 73).

[3] Mathews also attributes the faculty of "willing" to autopoietic entities other than biological individuals, such as rivers, hence her argument that we need to ask such questions as "what does the river want us to desire?" and then to adapt ourselves accordingly (Mathews 2011, 16).

[4] This is not to say that mutatis mutandis, Mathew's principle of least resistance could not potentially be integrated into the theoretical framework of the present article, most obviously with respect to the final section of the article (Nature as mentor), where I discuss the question of cooperation.

In recent years, the concept of autopoiesis has been extended beyond the realm of biology. Margulis and Sagan (1995) and Fritjof Capra (1997), for example, have applied the notion of autopoiesis to ecology and more specifically to Gaia theory (see also Dicks 2011). Key to this development is the notion of the trophic cycle, that is to say, the idea that nutrients circulate between producers (plants), consumers (insects, animals), and decomposers (bacteria, fungi), or, to put it in Margulis's terms, that "waste equals food" (Margulis 1998, 119). Ecological or Gaian autopoiesis may thus be said to depend in the first instance on the cycling of nutrients in closed loops, and, as such, is in line with Barry Commoner's view that the sustained existence of life on earth depends ultimately on the emergence of closed trophic loops (Commoner 1971, see also Dicks 2014).

But it is not only biological and ecological systems that may be viewed as self-producing. Edgar Morin, in particular, has argued that certain purely physical systems are also self-producing. In volume one of *La Méthode* (1977), Morin sets out to understand "the nature of Nature". This, he explains, is what the Pre-Socratics called "physis", an ancient and forgotten concept meaning "self-production", and which he thinks applies not only to living beings and ecosystems but also to such physical systems as stars and vortices, both of which, he argues, exhibit dynamic circular organizations. Without self-production, Morin further claims, there would be nothing but chaos. Without self-producing stars, the universe would have remained a chaotic "cloud" of predominantly hydrogen atoms. Without self-producing life forms, the earth would have remained a chaotic molecular "soup". And without the trophic loops characteristic of self-producing ecosystems, life on earth would quickly have reverted back to the molecular chaos from which it first emerged. Morin further points out that all these self-producing beings or systems do not only generate themselves, for in the course of their self-production they also generate the various elements which compose them: the heavier atomic elements in the case of stars; the various organelles and organs in the case of living beings; and a diverse range of biotic and abiotic components—new species, soils, the ozone layer, etc.—in the case of ecosystems.

Before considering the relevance of this to biomimicry, two further aspects of Morin's analysis of physis warrant further attention. The first is Morin's claim that physis has traditionally been completely absent from physics. Both the classical mechanics of the seventeenth and eighteenth centuries and the equilibrium thermodynamics of the nineteenth and early twentieth centuries were concerned with universal laws and forces.[5] It was only with the emergence in the second half of the twentieth century of non-equilibrium thermodynamics that it became a commonplace to study regularities and determinisms that hold only locally, and which arise thanks to the emergence of self-producing beings or systems that increase their own organization through the exportation of entropy to their environment, hence Morin's theorization of the notion of "endo-causality" (Morin 1977, 257–259) and Michel Serres's claim that the "new physics" is of the local, not of the global (Serres 1977). The second is the importance of the notion of self-production for ontology. According to Morin, "production" means "bringing into Being and/or existence" (Morin 1977, 157, my translation). Nature qua self-production, then, is the way that natural beings both come into and thereafter remain in existence. Without self-production, there would be nothing

[5] The same is also true of quantum mechanics.

but an undifferentiated chaos in which no entities could be said to exist in the sense of "standing out" (ek-sisting) with respect to an environment or background, a state of affairs that requires the emergence of some sort of boundary or limit. So, whereas a "hydrogen cloud" or "molecular soup" may be only be said to exist because they have been delimited as objects of study by human observers, stars or living beings self-produce and in so doing *set themselves apart* from what thereby becomes their environment.

But in what way is this view of Nature as physis appropriate for biomimicry? To answer this question, let us begin by noting that the view of Nature characteristic of traditional physics is clearly *inappropriate* in this context. Not only is it impossible not to follow the universal laws of Nature as set out in classical mechanics and equilibrium thermodynamics, but these universal laws do not in any way constitute a model, measure, and mentor that would allow us to "let beings be". The complete destruction of life on earth is no less compatible with the universal laws of physics than is constructive participation in its continued existence, for the very universality of these laws means that anything and everything that occurs necessarily obeys them. Moreover, it could even be argued that *deliberately following* the universal laws of physics, with only the abstract humanist principles of liberal democracy for ethical guidance,[6] is the principal cause underlying our currently destruction of Nature. The same cannot be said of physis. In contrast to the laws of classical mechanics and equilibrium thermodynamics, the local regularities studied within non-equilibrium thermodynamics make possible a renewed understanding of Nature as physis,[7] that is to say, as something that is essentially creative and productive, for in Nature's celestial, biological, and ecological forms, it is responsible for the creation of all self-producing beings and their components. This is not to say, of course, that biomimicry can ignore or discount the universal laws of physics,[8] but simply that what is specific and original to biomimicry is that it requires a set of laws, strategies, and principles that apply pertain to self-producing entities.

Viewing Nature as physis also allows us to go beyond the idea—encouraged by the etymology of the word "bio-mimicry"—that Nature is reducible to "life". Not only does viewing Nature as physis imply a distinctive philosophical perspective on the origin and essence of life (as autopoiesis or autocatalytic closure), but it also allows us to draw inspiration from both *ecological* and *physical* phenomena, which are not "alive" in any obvious sense of the word.[9] Regarding the former, consider Benyus's claim that "our transition to sustainability must be a deliberate choice to leave the linear surge of an extractive economy and enter a circulating, renewable one" (Benyus 1997,

[6] See Fukuyama (1993) for an analysis of the role progress in physics has played in the spread of liberal democracy.

[7] In *La Nouvelle Alliance* (1986), for example, Ilya Prigogine and Isabelle Stengers explicitly argue that thanks in large part to non-equilibrium thermodynamics the physical sciences are in the process of rediscovering *physis*.

[8] An important example of this is D'Arcy Wentworth Thompson's *On Growth and Form* (1961)—widely regarded as an important precursor to biomimicry—which analyses in considerable detail how such universal physical laws as gravity affect the form of both living beings and artefacts.

[9] In keeping with Maturana and Varela's view that autopoiesis is the defining characteristic of "life", it is generally argued that anything else that is autopoietic is also "alive". If, however, one equates autopoiesis not with life, but rather with Nature in the sense of physis, it is possible to see certain ecological and physical phenomena as autopoietic without considering them "alive".

56). This amounts to the claim that we should follow the specifically ecological from of self-production—the recycling of nutrients in trophic loops—thus abandoning the "linear, self-destructive course" that Commoner (1971, 299) sees as characteristic of contemporary technology. Ecological self-production, under this scenario, would become the basic model or source of inspiration for so-called "circular economies". As for strictly physical phenomena, it is interesting to consider Jay Harman's recent work developing technologies which imitate or draw inspiration from vortices. The key technology Harman developed was achieved by literally freezing a whirlpool and then using that as a model for a more efficient water mixer (Harman 2013, 51–64). Nuclear fusion provides another example of an emerging technology which draws on a physical process of self-production, in this instance one characteristic of stars. This is not to say, of course, that there may not be good reasons to reject nuclear fusion as a viable path for future energy production—Benyus's claim that "Nature runs on sunlight" would be the obvious starting point for discussion here. The point is rather that purely physical modes of self-production, as found in such entities as stars or vortices, may also provide models or sources of inspiration for human design.

But, even if we view Nature as physis, could it not be objected that this is also unduly limiting, for it problematically excludes drawing on physical entities that are not self-producing (or part of entities that are self-producing)? While a full answer to this objection would be beyond the scope of this article, a brief look at some of the entities within our solar system that fall into this category gives a preliminary indication of the complications—and even the dangers—of seeing such entities as models, measures, and mentors. It is hard to see, for example, how the moon, a passing meteorite, or the planet Venus might come to be seen as a model for biomimetic design. If anything, these entities—and particularly Venus, if it is true that it underwent runaway climate change—seem rather to provide models we should attempt to avoid.

To get a clearer understanding of the importance and appropriateness for biomimicry of viewing Nature as physis, let us briefly compare biomimicry with bionics. While the words "biomimicry" and "bionics" are sometimes used more or less interchangeably, a closer look at their origins and histories reveals a profound difference in their respective understandings of Nature. The word "bionics" was coined in 1958 by Jack E. Steele, perhaps as a neologism whose second part derives from the suffix "-ic", meaning "like", though it is sometimes also claimed that it derives from "electro*nics*" and even from "tech*nics*". Whatever the truth of this matter might be, it is clear that the career and research interests of its "discursive founder" played a significant role in shaping its subsequent trajectory. Steele was trained as an engineer, served in the US army, taught neuro-anatomy, and worked extensively on cyborgs. In keeping with this, Victor Papanek has noted that bionics may be interpreted in a "narrow sense" as "dealing with the interface between cybernetics and neurophysiology" (Papanek 1985, 189), and Steven Vogel has said of bionics that despite its broad potential scope, "'robotics' and 'artificial intelligence' now hold centre stage" (Vogel 2000, 250). As in the case of biomimicry, however, the original and longstanding association of bionics with neurophysiology, cybernetics, robotics, and AI points only *indirectly* towards the understanding of Nature on which it depends. So what is this understanding of Nature? Without going into extensive details, it seems plausible to say that the understanding of Nature implicit in bionics is essentially that of cybernetics, i.e. the view of Nature in terms of systems that use information to achieve heightened regulation and control, and which, in that respect, are no different from the artificial control systems developed within cybernetics. This is in keeping with an argument recently put forward by Daniel Wahl (2006), who claims that bionics aims primarily to increase our "control of Nature", and, as such, differs from biomimicry whose primary aim is "sustainable participation in Nature".

It is also significant in this context to note that the key thinkers of self-production and autopoiesis have all considered the general cybernetic tendency to see Nature in terms of the concepts of feedback, information, control, regulation, teleonomy, and so on, as radically inappropriate to a true understanding of the nature of Nature and instead draw attention to the basic way that Nature *differs* from technology: whereas technology is produced by *something else*, Nature *produces itself*. From this perspective, the cybernetic view of Nature implicit in bionics could ultimately be said to have *concealed* Nature qua physis, for it applies to Nature what Morin calls "the paradigm of the artificial machine" (Morin 1977, 195), and, in particular, the notion that natural beings are essentially cybernetic control mechanisms directed towards achieving certain "goals". This is not to say that biomimicry should not make use of heteropoietic concepts, hence the widespread references in biomimetic discourse to Nature's "design solutions" and "technologies", but it should not be forgotten that such language constitutes an abstraction performed by the scientist, for it is the scientist who delimits the relevant teleological mechanism or function (e.g. photosynthesis understood as having the goal of converting light energy into chemical energy), thus separating it out from the autopoietic unity (Maturana and Varela 1980, 86).[10] The importance of this cannot be underestimated. If, for example, we reduce biomimicry to the copying of nature's "technologies", but without integrating these technologies into circular systems, biomimicry will maintain us on a linear path of self-destruction. It is only when integrated or arranged into negentropic circular systems—whether of biological or technological nutrients (see Braungart and McDonough 2009)—that biomimetic design can be truly sustainable. Solar panels, for example, may be seen as taking inspiration from plants in their use of sunlight, but as long as these panels are produced via the extraction of non-renewable materials and discarded in landfills or incinerators, they will not be sustainable. In Nature, by contrast, photosynthesis is integrated into both autopoietic organisms (plants, algae) and autopoietic ecosystems (forests, etc.), and, as such, is sustainable.

3 Nature as Model

Now that we have demonstrated the importance and appropriateness for biomimicry of seeing Nature as physis, we may turn our attention to the question of how we may relate to Nature understood in this manner. Benyus explains the notion of "Nature as model" as follows: "Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g. a solar cell inspired by a leaf" (Benyus 1997). I name this the "poetic principle" of

[10] This is in keeping both with Foucault's remark that "knowledge is not made for understanding; it is made for cutting" (Foucault 1984, 88), but also with the etymology of the word "science", a word which originally meant "cutting".

biomimicry, for, as we will see, it calls on us to imitate or draw inspiration from natural processes of "bringing forth" (*poiēsis*).

At least since Plato and Aristotle, art has traditionally been seen in terms of the imitation (*mimesis*) of Nature or reality. A modern example of this way of thinking is Eric Auerbach's *Mimesis: The Representation of Reality in Western Literature* (Auerbach 1953). Moreover, as the sub-title of Auerbach's work clearly indicates, this tradition has typically interpreted *mimesis* in terms of representation, that is to say, as some sort of aesthetic depiction or description of reality. The problematic character of this traditional association of mimesis with representation has been highlighted by René Girard:

> The indifference and mistrust of our contemporaries with respect to imitation rest on the way they conceive it, which is anchored in a tradition which in the last analysis goes back to Plato. Already with Plato an essential dimension of imitation had been amputated. When Plato speaks of imitation, he does so in a way that anticipates and calls forth all later Western thought. The examples he proposes only ever bear on certain types of behaviour, manners, individual and collective habits, speech acts, ways of talking, and these are always *representations*. (Girard 1978, 17, my translation)

Girard then goes on to point out that Plato's overall view of mimesis excludes the copying or imitation of acquisitive behaviour, a phenomenon which he argues at length is the source of all conflict. However, while Girard is obviously right to note that mimesis may involve the non-representational imitation of human behaviour, his focus on the imitation of specifically *acquisitive* behaviour runs the risk of overlooking other forms of non-representational imitation, such as the imitation of productive techniques practised by other humans, or, more importantly as far as we are concerned, the imitation of Nature's ways of bringing things forth.

With a view to overcoming this lacuna, let us briefly consider the fact that contemporary advocates of biomimicry, such as Julien Vincent, are generally scathing of purportedly "biomimetic" designs—usually the work of architects or designers (not scientists or engineers)—that aim only to "represent" Nature (see Forbes 2005, 198). The fundamental objection to such designs can be stated as follows: they are merely *aesthetic*, for they aim to recreate the *sensations or perceptions* (*aisthēsis*) produced in us by Nature—usually what it looks like—and not its underlying *functions*. Indeed, in light of the biomimetic principle, "Nature fits function to form", such aesthetic representations of Natural forms would not ultimately appear to be biomimetic at all. Given our understanding of Nature as physis, however, to see Nature primarily in terms of "functions" is also problematic, for the identification of functions in Nature only arises through the abstraction or cutting out of linear processes, such as photosynthesis, from the circular wholes in which they are embedded. As far as we are concerned, this again reminds us of the importance of integrating or organizing biomimetic technologies into circular systems, thus imitating or drawing inspiration from Nature's specific mode of "bringing forth" (autopoiesis). In any case, biomimicry, on this view, is neither aesthetic nor functionalist but rather poetic, for it seeks above all to imitate Nature's basic way of bringing forth (autopoiesis).[11]

The fact that the "poetic principle" of Nature as model implies an imitation of Nature's way of bringing things forth, rather than an aesthetic representation of Nature's outward form, does not mean, however, that traditional theories of mimesis in terms of representation are of no relevance to our attempt to develop a philosophical understanding of biomimicry. Indeed, as we will now see, Paul Ricoeur's analysis of mimesis in Aristotle's *Poetics* allows for a powerful understanding of the concept which, mutatis mutandis, is highly relevant to the philosophy of biomimicry.

In *Temps et Récit* (1983), Ricoeur compares the differing conceptions of mimesis found in Plato and Aristotle. In *The Republic*, Plato affirms that a copy is necessarily degraded and inferior with respect to its model. Artistic representations, Plato can thus claim, are degraded copies of physical beings, which are themselves degraded copies of eternal ideas (Plato 1941). The overall schema here is clearly destructive and "entropic", for the general trend is for order to decline. In Aristotle's *Poetics* (1996), by contrast, Ricoeur notes that mimesis is a process reserved exclusively for humans (Ricoeur 1983, 72)[12] and that it is essentially creative. When Homer, for example, provides an artistic representation of the battle of Troy, he clearly omits all sorts of minor details, selecting only those elements of reality that are relevant to the plot (*muthos*), a process that gives rise to an original and clearly delimited composition, which, *as such*, has no counterpart in Nature or reality. It follows that while the work of art is for Aristotle clearly an instance of mimesis, it also brings forth a new composition not found in Nature (Ricoeur 1983, 79–86).

This distinction between the Platonic and Aristotelian conceptions of mimesis is of particular significance to contemporary debates surrounding the difference between—and relevant merits of—biomimicry and bio-inspiration. It is not infrequent for contemporary researchers to prefer the term "bio-inspiration" to "biomimicry", the main reason being that bio-inspiration appears to some to offer more leeway for innovation and creativity than biomimicry, which is sometimes associated with what Peter Forbes calls a "slavish copying of Nature" (Forbes 2005, 18). There is, however, an obvious complication here, namely, that Benyus and other proponents of biomimicry, such as Harman, regularly talk of biomimicry as involving *both* imitating *and* drawing inspiration from Nature. Shorn of its traditional association with representation, Aristotle's theory of mimesis as creative of something new—as opposed to Plato's theory of mimesis as making degraded copies of something old—provides an interesting

[11] It is interesting to note that both Benyus and Forbes, the authors of the two most important books to date on biomimicry and bio-inspiration, both have backgrounds in literature or poetry. Benyus has a degree in English literature and Forbes has worked as editor of the *Poetry Review* and also edited *Scanning the Century: The Penguin Book of the Twentieth Century in Poetry*. In keeping with this, both authors regularly evoke the "poetry" of Nature.

[12] This claim is significantly complicated by Aristotle's argument that all change—including the "self-changing" of living beings—can ultimately be traced back to an "unmoved mover" or "unchanging changer" (see Aristotle 2000), and that this primary entity constitutes a "model" imitated by the celestial cycles, which are themselves a "model" imitated by the cycle of the seasons, themselves a model for the circular generation of living beings (see Aubenque 1962, 497–502). One plausible explanation for these complications is Heidegger's claim that Aristotle's thought is situated at a historical crossroads between the original Pre-Socratic understanding of Being or Nature as physis qua "self-generation" or "self-placing-into-appearance" and the metaphysical tradition, which originates primarily with Plato (Heidegger 1998).

explanation of how this is possible: rather than rejecting mimesis in the name of inspiration, a decision that may be seen to rest ultimately on a Platonic understanding of mimesis as "slavish copying", we may instead come to see mimesis as itself a creative process that draws inspiration from Nature in such a way that an original composition emerges that does not necessarily try to reproduce every last detail of the natural models it imitates.

In addition to the criticism levelled at biomimicry under the name of bio-inspiration, it has also been argued that, if widely adopted, biomimicry would give rise to a world filled with imitations of Nature, which, over time, would replace their original models (see Mathews 2011, 20). Biomimicry, on this view, could give rise to a world full of "robotic bees" for use in pollination, "artificial trees" for sequestering carbon dioxide, and so on, but from which "natural"—i.e. self-producing—bees and trees are almost totally absent. Seen in this light, biomimicry would appear to be the ultimate ally for "weak sustainability"—the view that development is sustainable provided the total amount of capital, whether natural or artificial, does not decrease—, for, in allowing artificial capital to fulfil the same functions as natural capital, biomimicry could in theory help sustain an almost wholly artificial world.

Partly in response to this possibility, "bio-designers" have argued that design should aim not to *imitate* Nature but rather to *incorporate* it (see Myers 2014). As in the case of bio-inspiration, however, it would be a mistake to think that biomimicry and bio-design are opposed. To see this, it is helpful to consider John Todd's writings on "ecological design". Todd dedicated much of his practical research into designing sewage treatment plants—named "living machines"—which imitate the way natural wetlands treat wastes, and which to that end incorporate a diverse range of living beings also found in wetlands. These designs may clearly be considered to belong to both biomimicry and bio-design, a state of affairs which is in line with Todd's manifestly biomimetic view that biology is "the model for design" (Todd and Todd 1993, 12), but also with his demand "(t)hat design be sustainable through the integration of living systems" (Todd and Todd 1993, 64–68). This is in keeping, moreover, with Otto Schmitt's early understanding of what he called "biomimetics" as "developing physical *or composite bio-physical systems* in the image of life" (quoted in Vincent et al. 2006, my italics). As for Benyus, her chapter on biomimetic agriculture, which advocates farms modelled on prairies, clearly involves working with Nature, rather than replacing it with, say, industrially farmed monocultures or biomimetic foodstuffs synthesized in the laboratory. Moreover, while none of Benyus' principles concerning the human relation to Nature explicitly mention the integration of living beings into biomimetic designs, her claims that "Nature rewards cooperation", "Nature banks on diversity", and "Nature demands local expertise" together point towards the importance of cooperating with a diverse range of natural beings adapted to local conditions. Nevertheless, it is important to realize that biomimicry does not only advocate *integrating Nature into design* (at least where appropriate) but also *integrating biomimetic designs into Nature* (Benyus 1997; Wahl 2006; Braungart and McDonough 2009). Indeed, while Forbes may be quite right to say that "[w]hat makes bio-inspiration possible is the miracle that nature's mechanisms do not have to be alive to work" (Forbes 2005, 5), it is also true that simply making things that copy this or that natural mechanism is not in itself sustainable, for sustainability requires these mechanisms to be integrated into dynamic circular systems.

4 Nature as Measure

Perhaps the most significant difference between biomimicry and the related fields of bionics, bio-inspiration, and bio-design is that biomimicry puts forward two further principles that are without analogue in these other fields: "Nature as measure" and "Nature as mentor". Benyus describes the first of these—biomimicry's ethical principle—as follows: "Biomimicry uses an ecological standard to judge the 'rightness' of our innovation. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts" (Benyus 1997). Nature, it follows, does not only provide models from which we may draw inspiration; it also prescribes tried and tested standards which limit what we may and may not do. In this respect, Nature in biomimicry is again very different from Nature as it appears in classical mechanics or equilibrium thermodynamics. Within a philosophical framework which views Nature in terms of universal laws and forces, the limits imposed by Nature on our actions must necessarily be obeyed, the result being that the only genuinely *ethical* laws that govern human behaviour appear either as contingent human constructs or as flowing directly from abstract attributes deemed unique to humanity (freedom, reason, equality, etc.). In what follows, we will see that seeing Nature as physis or self-production provides a viable ontological ground for the biomimetic idea that Nature places *ethical limits* on our actions.

In our earlier discussion of physis, we noted that an essential aspect of self-production is the production of boundaries or limits. Indeed, it is precisely because self-producing beings delimit themselves from their environment that they exist. With this in mind, let us now turn our attention to the final two of Benyus's nine statements regarding how Nature does things: "Nature curbs excesses from within" and "Nature taps the power of limits". The first of these points to the fact that natural beings not only possess various limits without or beyond which they cannot exist but also—at least in some cases—that they possess the capacity of self-regulation such that the transgression of these limits may be avoided. Recognition of the fact that "Nature curbs excesses from within" could thus potentially allow us to follow Nature's lead and impose limits on our own current excesses (greenhouse gas emissions, overfishing, food waste, etc.), such that our actions fall back within the boundaries of the sustainable. Moreover, as the observation, "Nature taps the power of limits", tells us, these limits should not be seen as unfortunate restrictions on our freedom, but rather as powerful sources of creation and, as such, ultimately generative of different types of freedom. So, just as in great poetry the limits that give the poem form—genre, meter, etc.—give rise to all sorts of creative possibilities not present in prose, so the limits produced by Nature are likewise essential to its creativity.

Another important point to note here concerns the importance for biomimicry of seeing Nature *as* physis. History provides a certain number of prior cases in which Nature—viewed other than as physis—has been seen as measure. Social Darwinism, for example, saw Nature in terms of such principles as "natural selection" and "survival of the fittest" and then argued that because these principles are "natural" they constitute a measure or standard by which the "rightness" of humans and their institutions may be judged. This argument was then used to justify a wide variety of different economic, social, and political positions, including laissez faire capitalism, nationalism, racism, eugenics, and even certain variants of socialism (see Bowler 2009, 274–324). Three main philosophical arguments have been brought against "appeals to nature" of this sort. The first, associated with deconstruction and certain forms of constructivism, considers that the very concept or idea of Nature is itself a "construct", in which case Nature is not natural at all, but rather a product or invention of human beings often serving to "naturalize" various forms of hierarchy, oppression, injustice, and so on. The second is the argument associated with David Hume and others, according to which appealing to Nature constitutes a "logical fallacy", for it involves a logically unjustified leap from "is" (Nature does X) to "ought" (we should do X). The third is that in reducing human activity to an imitation of Nature, we leave no room for ways of being that are specific to humankind, and which, as such, in some sense "transcend" Nature. As we will now see, however, there are a number of reasons why the common contemporary rejection—at least outside of biomimicry—of appealing to Nature is problematic once we see Nature as physis.

The first reason concerns Heidegger's claim that the Greek conception of physis is "Being itself" (Heidegger 2000, 15). If this is true, then to take physis as measure is to follow the way of Being as opposed to the way of not-Being or nothingness.[13] Edgar Morin's study of physis clearly demonstrates why this is the case. In order for anything to "be" or "endure" ("*wesen*", Heidegger would say), it must either *be* a self-producing entity (as in the case of, say, living beings) or *constructively participate* in a self-producing entity (as in the case of, say, genes).[14] This view of Nature as physis also allows us to see the problem implicit in the nineteenth century assimilation of Nature to evolution or natural selection. Natural selection, as Kauffman has argued, is a *secondary* process operating on beings that in the first instance come to exist via the fundamental biological process that is autocatalytic closure (Kauffman 1995, 188, 274), hence his claim that "Darwinism is not enough" (Kauffman 1995, viii). This is in keeping, moreover, with the fact that Darwin's fundamental concern was not with the origin of Nature, or even of life, but rather with the origin of species. From this perspective, the basic problem with social Darwinism is not that it saw "Nature as measure", but rather that it assimilated Nature to Darwinian evolution.

The second reason concerns the deconstructionist critique of Nature. This critique is based on the following argument: everything is a construct; therefore there's no such thing as Nature. Interpreting Nature as physis makes it possible to accept the premise of this argument, while denying its conclusion. While the interpretation of Nature as physis is in agreement with the claim that everything is in some sense a construct (or product), it also implies a fundamental distinction between two types of construction (or production): construction of the self and construction of something other. This in turn reveals the metaphysical nature of the deconstructionist interpretation of Nature: it assimilates Nature to the fixed and unchanging ideas behind things, and then goes on to "deconstruct" this view by showing that these ideas are socially constructed, historically dependent, textually embedded, and so on. In short, it involves a *deconstruction of*

[13] According to Richard Capobianco, Heidegger himself thought that we should take physis as measure. Indeed, Capobianco even goes so far as to claim that "[t]he core matter for Heidegger—and for those inclined to his thinking—is that physis is the measure, not *Dasein*." (Capobianco 2014, 63)

[14] There are certain exceptions to this rule, such as junk or harmful DNA, but these are necessarily exceptions, for once they rise beyond a certain critical threshold they will destroy the autopoietic entity in which they reside. A similar point goes for the linear, extractive technologies of contemporary humans. It is the scale at which they operate which explains their destructiveness.

metaphysics and not an *alternative to* metaphysics. Viewing Nature as physis, by contrast, constitutes a genuine alternative to metaphysics, for it does not suppose that the being or essence of a natural entity is some sort of fixed and unchanging idea: its being or essence is rather the specific way that it self-produces, and this is neither a human construct, nor a fixed and unchangingiIdea. To understand the being of a natural entity, then, is not to understand the idea behind it, a way of thinking that continues to suppose the technological model of Platonism, according to which natural entities are physical realizations of underlying models or blueprints (ideas), but rather to understand the contingent specificities of its self-production. A distinctive contribution of biomimicry is then to add that these contingent specificities may themselves become models for human design, at least provided the resulting designs are themselves integrated or arranged into negentropic circular organizations.

The third reason concerns the Humean objection that one cannot argue from "is" to "ought" and thus from what Nature does to what we should do. There are two main ways that one might respond to this objection. The first is simply to note that biomimicry does not claim that there is any *logical* reason why we should do as Nature does: it may be *wise* to do as Nature does, but that does not mean that doing so follows *logically* from the nature of Nature. The second consists in interpreting physis not simply in Morin's predominantly *systems-theoretical* sense of the word, but also in Heidegger's *phenomenological* sense as "*poiēsis en heautōi*" (Heidegger 1993, 317), or, in English, "plac[ing] itself into appearance" (Heidegger 1998, 222) or "placing itself into the open" (Heidegger 1998, 208). Seeing *poiēsis* in this way entails a "correlationist" understanding of physis, according to which it is in the very nature of physis to appear in the "open", where the open is understood as a "clearing" specific to humans wherein beings are understood and interpreted "as" such and such. On this view, it belongs to the very nature of physis to be open to understanding and interpretation, a state of affairs which also applies to the principles of Nature as model, measure, and mentor. I propose to call this phenomenological and hermeneutical interpretation of Nature qua physis "enlightened naturalism" (*naturalisme éclairé* in French), for it does not see Nature as a set of indisputable facts or things that are the case independently of human existence, but rather as something that appears in the "open" or "clearing" (*clairière* in French), and thus as something that is constitutively open to understanding and interpretation "as" such and such, including being seen "as measure".

The fourth reason concerns the objection that biomimicry reduces human existence to the imitation of Nature, thus leaving no room for all that is distinctively human, i.e. for *human nature*. For example, the idea of taking social insects or animals, such as ants, bees, birds, or fish as models or sources of inspiration for human behaviour and social organization, as advocated by Miller (2010) and Lovelock (2014), runs the risk of concealing, overlooking, or even eliminating what is specific to human nature. In response to this objection, let us begin by noting that the nature of a natural entity is the specific way or ways that it produces itself. This principle may also be applied to human beings: what is specific about the ways that we humans produce ourselves? While it would exceed the scope of this article to provide a detailed answer to this question, the simple fact of asking it is revealing, for it reminds us that we humans are likewise self-producing, and in that respect part of Nature. This is not to say that we do not also produce things other than ourselves, but rather that even this production of the other ultimately belongs to the specific way or ways we produce ourselves. This overall approach in turn raises the possibility of taking *human nature* as a model or source of inspiration. For example, seeing humans not as free, rational, and equal (at least as these concepts were understood by Enlightenment humanists), but rather as some sort of "open" or "clearing" in which Nature presents itself—a position I call "enlightened naturalism"—could potentially allow us to develop various institutions, ways of thinking, and so on, that preserve the distinctively human clearing wherein the self-disclosure of Nature, including human nature, may take place.

5 Nature as Mentor

Benyus explains the "epistemological principle" of biomimicry as follows: "Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can *extract* from the natural world, but on what we can *learn* from it" (Benyus 1997). Later on, she makes a similar point, claiming that thanks to biomimicry we may come "not to learn *about* nature so that we might circumvent or control her, but to learn *from* nature, so that we might fit in, at last and for good, on the Earth from which we sprang." (Benyus 1997, 9) In the light of our analysis of Nature as physis, the basic epistemological shift here may be understood as follows: rather than seeing the human subject as the primary locus of knowledge and wisdom, and Nature as an object about which knowledge may be obtained, Nature becomes the primary locus of knowledge and wisdom, which it discloses to humans—and to humans alone—in the course of its self-disclosure. It is this radical shift, no doubt, that explains why, in her explanation of the "epistemological" principle of biomimicry, Benyus claims that it introduces a new "era".

In order to get a better understanding of how the epistemology of this era differs from those that have dominated Western thought from the Middle Ages onwards, let us examine what a variety of thinkers have had to say about one single being: the cherry tree. According to Feuerbach's critique of Christianity, it projected Man's fundamental traits into God and at the same time "alienated" them from himself. In response to this, he claimed that Man—understood as a species—could re-appropriate for himself the various attributes formerly projected into God. The attribute of omniscience, for example, could be re-appropriated by the human species via the collective endeavours of scientists (Feuerbach 1843). So, while any individual scientist could not know everything there is to know about the cherry tree, collectively, it would be possible for scientists to obtain a complete understanding of it. Knowledge, in this instance, is clearly knowledge possessed by human subjects about the properties of objects that may be perceived by the senses (in some cases via scientific instruments).

Feuerbach's position was in turn criticized by Marx. For Marx, the only reason Feuerbach could take the cherry tree as an object of "sensuous certainty" was because it had been "transplanted by commerce into our zone" (Marx 1977, 174). This shows, Marx thinks, that more primary than the collective pursuit of *knowledge about Nature*, is the *exploitation of Nature* as a resource for economic development. Knowledge here is still on the side of the human subject, but the human subject is no longer a disinterested observer applying rational analyses to empirical data made available via the senses, but an interested economic actor. Marx's thought thus has much in common with Heidegger's prioritization of the ready-to-hand (*das Zuhandene*) over the present-at-hand (*das Vorhandene*) in *Being and Time* (1995), which it to say, of the usable over the representable, but also with what Richard Rorty (1991) sees as the basic tenet of American pragmatism: that *coping* with reality is prior to *copying* reality, where copying is understood in terms of representation. Moreover, once the cherry tree comes to be seen from an essentially pragmatic or utilitarian perspective, questions immediately arise about who owns it, who benefits from it, who suffers from the pesticides used on it, who has access to knowledge about it, how they use that knowledge, and so on. Humankind, in this context, is not united in the pursuit of omniscience, but riven by economic, social, ecological, and other forms of conflict, as has been theorized by postmodernism. Knowledge—which may henceforth be both theoretical (knowing that) and practical (knowing how)—thus becomes increasingly to be associated with various conflicting forms of power.

With the advent of biomimicry, the epistemological status of the cherry tree changes yet again. Indeed, in the work of Michael Braungart and William McDonough,[15] the cherry tree becomes the paradigmatic example of the knowledge and wisdom embedded in Nature:

> The [cherry] tree makes copious blossoms and fruit without depleting its environment. […] As it grows, it seeks its own regenerative abundance. But this process is not single-purpose. In fact, the tree's growth sets in motion a number of positive side-effects. It provides food for animals, insects, and microorganisms. It enriches the eco-system, sequestering carbon, producing oxygen, cleaning air and water, and creating and stabilizing soil. Among its roots and branches and on its leaves, it harbours a diverse array of flora and fauna, all of which depend on it and on one another for the functions and flows that support life. And when the tree dies, it returns to the soil, releasing, as it decomposes, minerals that will fuel healthy new growth in the same place. (Braungart and McDonough 2009, 72–79)

As this passage clearly implies, Braungart and McDonough understand the cherry tree neither as something that is simply to be *copied*, where copying is understood as the more or less accurate and coherent representation of objects perceived by the senses, nor as part of a world characterized by pragmatic efforts to *cope* with trials of strength between different actors, but rather in terms of its *copiousness*. The cherry tree, as the etymology of the word "copious" tells us—from "*com-*", meaning "with", and "*opus*" meaning "work or produce in abundance"—*produces in abundance by co-operating with the beings around it*, a fact that resonates with Benyus's claim that "Nature rewards cooperation". To say this is not, however, to romanticize Nature, as if Nature exhibits only cooperation and not competition, but rather to note that competition—whether in organisms (between genes, cells or organs) or in ecosystems (between individuals or species)—is only sustainable thanks to the self-production of the basic whole in which the competing parties reside, hence Braungart and McDonough's emphasis on the fundamental importance of imitating natural cycles of

[15] There is no suggestion in their text that Braungart and McDonough chose the example of the cherry tree because of the role it has played in the history of philosophy. Indeed, the choice would appear to be entirely serendipitous.

biological nutrients. This implies that there must be a minimum level of cooperation between producers, consumers, and decomposers, for without that cooperation, the trophic loops on which all life ultimately depends would not exist. Moreover, all self-producing entities—and not just strictly biological ones—may be seen as "embodied minds", whose basic nature is not to represent the world, but rather to adjust constantly to perturbations in such a way that they may endure (Varela et al. 1993). Nature, in short, is itself a cognitive or mental process, and it is to this mental process that we must turn in search of enlightenment.

6 Conclusion

The present article has discussed four key areas of inquiry which, I have argued, constitute the basic research framework of the philosophy of biomimicry. The first of these is the ontological question of the "nature of Nature". The second, third, and fourth areas deal with the three key biomimetic principles that structure the human relationship to Nature, each of which corresponds to—and at the same time radically reconfigures—a traditional field of philosophical inquiry: poetics and aesthetics (Nature as Model); ethics and politics (Nature as measure); and epistemology and philosophy of mind (Nature as mentor). Of particular importance to my discussions of these four areas has been the attempt to draw constructively on various objections that could be made with respect to Benyus's seminal, but still embryonic, vision of Nature. Indeed, this vision could be—and in some cases already has been—criticized as: descriptive and ad hoc; advocating a slavish copying of Nature; entailing the replacement of Nature by technological imitations; committing the logical fallacy of reasoning from "is" to "ought"; "naturalizing" ways of doing and thinking ultimately invented or constructed by humans; reducing human activity to the imitation of the non-human, thus overlooking what is specific about human nature; involving a romantic or idealistic celebration of Nature as free from all strife and competition. Of particular importance to overcoming these objections, I believe, is the development of a philosophical paradigm I call "enlightened naturalism", which consists in seeing Nature as physis, physis as "self-bringing-into-the-open", and the open as a "clearing" specific to humans, in which, subsequent to Nature's initial self-disclosure (as self-disclosure), it may be taken as model, measure, and mentor. More generally, I also believe that the overall approach of the present article—with its focus on philosophical analysis of biomimicry's basic concepts, situating biomimicry in a broad historical context, analysing its relation to art and literature, and exploring how it may help us re-think human nature—may also play a role in widening the scope of future research in this field, which would henceforth extend beyond the current research paradigm of collaborations between scientists (biologists, ecologists, etc.) and technologists (engineers, architects, designers, etc.) so as to include research in philosophy and the humanities.

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