Synthese (2023) 201:112
https://doi.org/10.1007/s11229-023-04099-1

ORIGINAL RESEARCH

Teleology and function in non-living nature

Gunnar Babcock[1]

Received: 18 July 2022 / Accepted: 14 February 2023 / Published online: 16 March 2023

Abstract
There's a general assumption that teleology and function do not exist in inanimate nature. Throughout biology, it is generally taken as granted that teleology (or teleonomy) and functions are not only unique to life, but perhaps even a defining quality of life. For many, it's obvious that rocks, water, and the like, are not teleological, nor could they possibly have stand-alone functions. This idea - that teleology and function are unique to life - is the target of this paper. I begin with an overview of McShea's *field theoretic* account of teleology. I start with the field theoretic account because it presents a promising analysis of teleological systems. It is promising because, in not making any assumptions about life's special status in teleological systems, it avoids counterexamples that have problematized other accounts. I then consider some of the prominent efforts that some have made to avoid ascribing functions or teleology to some form of inanimate nature. In my assessment, none of the efforts are successful. I conclude by offering mineral evolution as a case study to show how inanimate nature can be both teleological and functional. The evolution of mineral species reveals that teleology and function extend to inanimate nature, and that teleology and function come in degrees.

Keywords Teleology · Function · Life · Minerals · Selected effects · Multiplication

✉ Gunnar Babcock
gunnar.babcock@duke.edu

1 Department of Biology, Duke University, Durham, NC 27708, USA

1 Introduction

There is a general assumption that teleology and function do not exist in inanimate nature. Throughout biology, it is generally taken as granted that teleology (or teleonomy[1]) and functions are not only unique to life, but perhaps even a defining quality of life (see e.g. Pittendrigh, 1958; Monod, 1971; Dobzhansky, et al. 1977; Corning, 2019; Vane-Wright, 2022). For many, it's obvious that rocks, water, and the like, are not teleological, nor could they possibly have stand-alone functions. Perhaps the clearest statement that encapsulates a view along these lines comes from Dobzhansky: "Purposefulness, or teleology, does not exist in nonliving nature. It is universal in the living world. It would make no sense to talk of the purposiveness or adaptation of stars, mountains, or the laws of physics." (1977, p. 95). This idea - that teleology and function are unique to life - is the target of this paper. I'll argue that making such assumptions has clouded our ability to understand teleology and function. This is because it seems most accounts of both teleology or function have been unable to avoid inadvertently ascribing functions or teleology to some form of inanimate nature (see e.g. Bedau, 1991; Toepfer, 2012; Bourrat, 2021). Due to this lack of success, it seems the obvious path forward is to concede that teleology and functions, contrary to intuition, are found throughout inanimate nature.

To argue for this, I begin by analyzing *field theory* – a theory originally put forward in a paper by McShea in 2012, which has subsequently been further developed by McShea, Lee, and myself. Field theory has the virtue of being able to account for teleological systems in a wide variety of living, artifactual, and natural but non-living entities. McShea's insight is that teleology has to do with complexity rather than with internality, and this is what eluded Nagel (1979) and Mayr (1988) in their analyses. I then consider Mossio and Bich's organizational account of teleology (2017) and Garson's generalized selected effects account of function (2017), as both attempt to restrict the scope of function and teleology so as to exclude certain inanimate entities. In my assessment, neither of the attempts are ultimately successful, though the accounts themselves are still of value. I conclude by offering mineral evolution as a case study to show how inanimate nature can be both teleological and functional. I do this by applying the explanatory resources of both field theory and a revised generalized selected effects account of functions to the evolution of minerals as presented in Hazen et al. (2008). The evolution of mineral species reveals, not only that teleology and function extend to inanimate nature, but also that teleology and function come in degrees, as others, like Matthewson (2020), have suggested.

[1] Since Pittendrigh (1958) introduced the term "teleonomy" there's been a debate how best to deploy the notions of 'externalist teleology', 'internalist teleology' and 'teleonomy' (also see Mayr, 1988; Corning, 2019). Throughout this paper, I use 'teleology' with the aim of capturing all three.

2 Chair functions

Before turning to the question that is at the heart of this paper, a word is needed about the relationship between functions and teleology, and how it will be treated. At risk of inviting the ire of those who research teleology and/or function, this paper considers accounts of both teleology and function alongside one another. In doing this, I bracket many of the questions that have been raised about the relationship between functions and teleology, which Wright (1973) in particular, drew attention to. I've chosen to do this because those who theorize about function and teleology often share the same assumption noted in the introduction, i.e. that neither is found in non-living nature. As a result, accounts of both teleology and function have been critiqued on very similar grounds: they unintentionally ascribe goals or functions to non-living entities. I believe the similarities between the assumptions made about the scope of functions and teleology, and the critiques they both suffer as a result, makes them worthy of side-by-side investigation. The precise relation between function and teleology does not figure largely in this matter, in my view. Still, let's briefly acknowledge why function and teleology are not equivalent.

In accord with the analytic tradition, Wright (1973) carefully carved teleology and function apart from one another. He observed that teleological explanations apply to behaviors, whereas some objects that are incapable of behaviors nevertheless possess functions. For example, Wright notes that a chair has a function, but it does not have any goals because it cannot act. Following such observations, it's apparent that teleology and function are not mutually inclusive despite the tendency many have to conflate the notions. And insofar as one accepts that teleology applies only to behaviors there is no reason to think the distinction doesn't hold.

Still, teleology and function are often closely linked as "functional ascriptions are often thought to be a type of teleological explanation." (Garson, 2008, p.525) So, despite their differences, functions are often a result of a broader teleological system. To see what I mean, reconsider Wright's behavior-less chair. A chair might only have a function and no goals because it lacks the capacity to act. But it seems quite possible to imagine that a chair's function as a sitting device only comes about in the context of a larger goal directed system that includes people who have had the *goal* of sitting. Without that broader context, it wouldn't have a function. Similarly, one might think we can only ascribe functionality to an organism's traits by making certain background assumptions; for example, that organisms have the *goals* of survival and reproduction.[2] In essence, it's not entirely clear whether there would be functions if there were not larger goal directed systems. Wright might complain about this move, but I will make it and leave it to others to decide whether chairs are functional in a world where there have never been people with the goal of sitting in them. In any case, moving forward let me stipulate that throughout this paper I make the background assumption that functions, while different, nevertheless imply teleology. But to be very clear, in comparing teleology alongside functions, I am not implying that they are equivalent. Instead, the comparison is being made because of the shared

[2] For two fairly explicate statements saying that survival and reproduction are *the* goals of organisms, see Goudge (1961) or Ayala (1998), as observed in Toepfer (2012, p.117).

tendency many have in thinking that neither functional nor teleological systems are found in inanimate nature.

3 Balls in bowls

The next three sections address three separate cases where non-living systems are presented as posing a hurdle for three separate accounts of teleology and function. These are Nagel's (1979) systems-theory of teleology, Mossio and Bich's (2017) organizational account of teleology, and Garson's (2017; 2019) generalized selected effects account of function. This section begins with the first of these, where Nagel attempts to delimit the scope of his systems-theory from including a non-living example that he, himself, raises as a possible hurdle for his account. My assessment is that Nagel's effort isn't satisfactory for reasons found in McShea (2012). To see why this is, let's begin with an overview of field theory.

The theory of teleology put forward in a series of papers by McShea, myself, and others (McShea, 2012; 2016a; 2016b; Lee and McShea, 2020; Babcock and McShea, 2021; 2022) argues that teleological systems are a result of what we call external, upper level fields which direct the entities within them *persistently* and *plastically*. For McShea and myself, although these two features do not define teleology, they are the hallmarks of teleological systems. In fact, McShea borrows these features from Nagel's (1979) systems-theory of teleology. McShea's characterization of persistence and plasticity is:

> "Persistence is the tendency for an entity that is following a particular pattern, a behavioral trajectory, to return to that same trajectory following perturbations that cause it to depart from the trajectory. And plasticity is the tendency for an entity to find a particular trajectory from a variety of different starting points." (McShea, 2012, p. 664).

A torpedo that targets a ship regardless of where it was launched from exhibits plasticity. A torpedo also exhibits persistence when it reorients its trajectory back at the ship after having been pushed sideways by a current. Nagel, McShea, and others suggest that otherwise seemingly disparate teleological systems tend to share these two features. However, to understand field theory it is key to see that external, upper level fields are what generate persistence and plasticity. To see why, consider McShea's example of a bacterium's food seeking behavior. When a bacterium is swimming in a chemical gradient emitted from some food it's seeking, it behaves with persistence and plasticity. No matter where the bacterium begins within the gradient, nor how it might get knocked off course once in the gradient, it continues on its trajectory towards the food. Why? The spatial field of the gradient. It is responsible for the bacterium's end-seeking behavior. Absent the gradient the bacterium would not present anything akin to teleological behavior. And while there are many more details, this is the core of field theory.

However, the feature of field theory that's most important to this paper is that it differs from alternative accounts of teleology because it presents many examples of teleological systems that extend far beyond the paradigm of organism-centric cases, which tend to be the focus of many of other accounts. In contrast, field theory goes out of its way to explicitly argue against making a division between nature and artifacts (Babcock & McShea, 2021). In seeking to explain goal directedness generally, rather than focusing on the teleological behaviors of organisms, field theory not only presents a framework that is able to accommodate the extension of teleology to natural but non-living entities, but it actually anticipates this as a consequence of a more comprehensive account. External fields act on all sorts of entities. And proponents of field theory offer multiple examples of natural, artifactual, and natural non-living entities that are all teleological (McShea, 2012, 2016a, 2016b; Babcock and McShea, 2021, 2022). Perhaps the clearest example that illustrates their extension of teleology to non-living entities comes in McShea's (2012) discussion of a ball in a bowl, an example he borrows from Nagel (1979). It shows how McShea's analysis of non-living entities differs from others. So, let's begin with the ball in the bowl.

For Nagel, a ball circling in a bowl presents a counterexample to his systems-theory of teleology. It's a problem because a ball circling downward towards the bottom of a bowl exhibits persistence and plasticity. No matter where the ball starts in the bowl, nor whatever might disrupt its rolling, it ends up at the bottom of the bowl. So even though Nagel is willing to let certain artifacts be teleological, like homing torpedoes, the ball in the bowl presents a bridge-too-far. This has sometimes been dubbed the "problem of vacuousness" in the literature.[3] For Nagel, it's a problem if the ball's behavior is the direct result of the laws of nature. To block an outcome where balls in bowls count as teleological, Nagel makes a move that is echoed in Mayr's division between teleomatic and teleonomic processes (Mayr, 1988). Both Nagel and Mayr suggest that certain internal features of an entity must be the cause of natural teleology, not just the laws of nature. For Mayr, these were what he called "teleonomic" processes. A teleonomic system is internally regulated by programs, which, in biology, he believed were primarily found in DNA.[4] And so, because the cause of the ball's teleological behavior was gravity and not an internal program, for Mayr it's not teleonomic, it's "teleomatic", which means it's just a goal directed process that comes from the laws of nature. Mayr presents a rock falling in a well as an example of a teleomatic process (see Mayr, 1988, p.44). For Nagel, a teleological process must arise, not necessarily from a program, but from another feature of the internal structure of an entity. He required there to be some degree of independence, or demarcation, between different internal mechanisms contained with an entity for teleology to arise. A homing torpedo has this, as it contains internal mechanisms that are independent of each other. For example, demarcating one jet on a torpedo from another jet on it, noting their ability to act independently of each other, helps account for the torpedo's goal directed behavior. A ball lacks these kinds of independent parts. So, Nagel's cut between the internal workings of an entity and what is a direct result of the laws of nature allow him to say that, despite the persistence and plasticity

[3] Garson (2008) presents a good overview of this issue on pp. 540-1.

[4] As Corning (2019) points out, Mayr's division between teleology and teleonomy has subsequently come under heavy criticism and has largely been abandoned, although the term "teleonomy" continues to be preferred over "teleology" in biology because it indicates an internal teleology.

exhibited by the ball, it is not teleological (or teleonomic using Mayr's language). McShea (2012) provides a different analysis.

McShea suggests that the primary difference between those processes that are generally acknowledged to be teleological and what Nagel and Mayr would consider to be only seemingly teleological systems, like the ball in the bowl, is not so much a matter of internal versus external, but rather one of mystery and complexity (McShea, 2012, p. 680). For McShea, the apparent difference has to do with the complexity of the explanation. Because we have a relatively firm grasp on the laws of nature the actions of a ball in the bowl are less mysterious than in more typical cases of teleology, like homing torpedoes, human behaviors, tropisms, or organismal development. An explanation of the ball's behavior only requires reference to several well-established laws. However, without an understanding of such laws, the actions of the ball might appear more mysterious, and subsequently more teleological.

I believe McShea's point can be seen by taking a historical perspective. Aristotle's teleological framework struggled to account for why inanimate, natural objects, like rocks, tended to move downward. For Nagel and Mayr such teleomatic processes require special treatment because they look like odd outliers that only by coincidence appear teleological. But notice, falling rocks only appear as outliers when you have Newton's shoulders to stand upon. Without a knowledge of gravity, one might be forced into the awkward position, like Aristotle was in, of having to offer a story about how it's in the nature of rocks to go downward. This might entail having to attribute something like an internal nature to rocks.[5] From this vantage point, it's understandable why the tendency of rocks to go down looked unavoidably more mysterious and more teleological to Aristotle. Unlike Nagel and Mayr, he didn't have Newtonian laws to draw upon when looking for explanations. Nagel acknowledges as much: "the behavior of the simple pendulum is *not* goal-directed relative to the assumptions of Newtonian mechanics and gravitational theory, before Newton's time that behavior might very well have counted as goal-directed" (Nagel, 1979, p.290). Understanding gravitational fields demystified many fairly simple teleological systems, like a rock's seeming end-goal of downward-ness. And since it has seemed natural to declare that things like pendulums and rocks are, therefore, not goal directed. But perhaps such declarations have been too quick.[6]

To see why let's return to the bacterium in the food gradient, but let's slightly alter the example to get at the idea of mystery. Imagine that in the future we discover a new law of nature that, with almost perfect mathematical precision, predicts the food seeking behavior of microbes. With such a law it seems quite likely that microbes would look less teleological, and instead more mechanical and deterministic. They would look more like falling rocks. McShea's point seems to be that such a discovery wouldn't suddenly entail that we've been wrong all this time – that microbial food-seeking behavior is *not* teleological. Quite the contrary. The persistence and plasticity that microbes exhibit when seeking food in a gradient would still be teleological as nothing about their behavior changes with the discovery of the law. Instead, the

[5] There are, of course, many ways to interpret Aristotle's explanations of inanimate nature. See Cohen (1994) for an analysis of the various interpretations of Aristotelian accounts of motion/change.

[6] Also see Bedau (1992) for an argument against this division, as it has been made by systems theorists.

discovery of such a law would make their persistent and plastic behavior less mysterious, not less teleological. This seems to be his point about the ball in the bowl. The ball is teleological, but just barely. It's just "barely" teleological because the range of behaviors and the degrees of complexity between the ball, the bowl, and the gravitational field it finds itself within are far fewer than what's found in other more complex teleological systems, like a food-seeking bacterium. An explanation of the ball's end seeking behavior requires far fewer principles than what is observed in more complex systems.

Given its minimal degree of teleology, what then is the correct analysis of the ball in the bowl? To some extent, McShea's field theory aligns with that of Nagel or Mayr. Gravity is the force guiding the ball towards the bottom of the bowl. The difference is that McShea would say gravity is an upper level field, and that field is the primary source of the ball's teleology. External fields are always the source of teleology according to field theory. The curvature of the bowl directs the ball up and down, and side to side, while gravitational pull assures that it will arrive at the lowest point. And so, the ball's persistence and plasticity, as it moves towards the lowest point, are quite limited and quite minimal. The ball might circle the bowl for several seconds, but it is assured to reach its end in very short order. However, compared to a falling rock, the ball's movements away from the bottom of the bowl, however short lived, demonstrates a higher degree of teleology than a rock. A rock falls directly to the ground with almost no ability to deviate from its course. The torpedo's persistent and plastic behavior is far more resistant to the fields directing it than either the rock or the ball. But notice that Mayr is right in saying that the rock's falling is teleomatic. *Teleo*matic processes are after all, still, goal directed processes. McShea's theory reveals that the real difference between these cases has to do with degree. Because simple teleological systems are almost perfectly predictable there's no mystery to the rock's behavior. Hence, the less persistence and plasticity there is in the teleological system, the less typically teleological it appears.

Granting, as Mayr does, that even falling rocks have the smallest shred of goal directedness, and then incorporating McShea's field theory, we have an account of how teleological systems work that's consistent with the persistence and plasticity that Nagel observed in certain inanimate systems. Applying the principles of field theory, a rule of thumb seems to be: *degrees of teleology correspond to the amount of persistence and plasticity an entity or system exhibits*. In other words, the greater capacity something has to deviate from a particular end-oriented trajectory and then return to the trajectory, the higher its degree of teleology. This kind of capacity to deviate from an end is close to what McShea and I have elsewhere called *freedom* (see McShea, 2016b; Babcock and McShea, 2022). A falling rock has almost no persistence and plasticity, and so it has almost no freedom. Hence it has a very low degree of teleology. Organismal development or a human behavior exhibits very high degrees of persistence and plasticity, and so they have more freedom, and hence they have much higher degrees of teleology. In this way, field theory shares a parallel with the general argument for a graduated account of function presented in Matthewson (2020). However, the accounts differ insofar as Matthewson grounds his argument in nuanced analysis of the varying degrees of natural selection, whereas field theory presents persistence and plasticity as providing a graduated view of teleological systems.

I'll end this overview of field theory with a final observation. There is a certain underlying irony that becomes clear in taking a field theoretic approach to teleology. The astonishing success the field concept brought to physics when Faraday first deployed it, and when it was later, further developed by Maxwell[7], has rendered what once appeared teleological (like falling rocks) to now appear devoid of teleology. It's ironic that as a teleological system is more aptly explained, it often tends to appear less teleological. But if field theory provides the correct analysis of teleology, the field concept's success in physics seems to be a testament to the power of how identifying fields is key to understanding teleological systems. Looking at the world with this lens reveals that persistence and plasticity are relatively commonplace… and so is teleology. What, then, are we to make of the various accounts of teleology and function that suggest such systems are unique to living, animate entities, if persistence and plastic systems are so commonplace?

4 Hurricanes and water cycles

In this section, I look to a recent account of teleology presented in Mossio and Bich (2017). Though there are many important differences between Pittendrigh, Monod, Dobzhansky, Corning, and what we find in Mossio and Bich, they all see teleology as being a primarily intrinsic or internal phenomenon. And one that is largely unique to living nature. I look to their account because it presents one of the more compelling contemporary approaches to making the division between animate and inanimate nature by looking to self-organization and self-maintenance to ground teleology. While their organizational account makes many important observations about the structure of living systems, ultimately, I believe it falls short of providing a method that separates living systems from non-living systems. This result shouldn't be surprising if field theory is accurate, because it shows teleological systems are ubiquitous and they are generated by upper level, external fields, in both living and non-living systems.

Mossio and Bich's organizational account argues that teleological systems can be naturalized by seeing that teleology is the result of self-determining dissipative structures which achieve their determination via self-constraint. I'll expand on why they take this to be the case in short order, but first let's note that if their account is right it not only means that natural selection is *not* the source of teleology, it also means that because balls in bowls and falling rocks are not self-maintaining systems, they are not teleological. Hence, it would mean field theory does not provide the right analysis of teleology.

The organizational account approaches teleology by considering the self-maintaining organization of structures found in various areas of biology. The authors argue that the self-maintenance of seemingly internally driven systems requires some kind of teleological explanation. They suggest self-maintaining systems are unique

[7] See McMullin (2002) for an enlightening history of the field concept.

insofar as they tend to have "closed" causal regimes. To oversimplify their account (and the other literature on teleology that they carefully build upon), they argue that the self-maintaining properties of certain non-equilibrium thermodynamic systems are what makes them teleological. This means Mossio and Bich are primarily concerned with biological organisms (though they acknowledge that their account could possibly extend to other biological systems such as super-organismal entities or ecosystems). What is unique to these biological structures is that they contain "networks of mutually dependent constitutive constraints" (Mossio & Bich, 2017, p.1113). Key to their account is distinguishing between two kinds of circular causal regimes that might provide networks of interdependent constraints. On the one hand, they suggest there are *cycles* and on the other hand there is *closure* (see Mossio and Bich, 2017, p.1105). Cycles are found throughout various dissipative structures, such as candle-flames, water cycles, hurricanes, or cyclones. These can be described at one level of causation, and they are the result of external constraints. In contrast, closed causal regimes are unique to biological entities and they require two levels of causation. A causal process maintains itself by providing an outlet for processes at another level of causation in a teleological system. Unfortunately, Mossio and Bich do not provide an example to explicate what these two levels look like in closed causal regimes, which makes the actual operation of a closed causal regime opaque. However, much to their credit, they tackle head on a problem their account faces. This problem is that there appear to be self-maintaining systems that extend beyond the biological world, which in turn would mean there's teleology in the non-living world. They see this as a hurdle that must be overcome in order to naturalize teleology (Mossio & Bich, 2017, p.1114). But why does extending teleology to inanimate nature pose a problem for the naturalization of teleology?

The idea that naturalizing teleology requires locating a bright line that confines teleology to the living, biological, animate world runs deep in theorizing about teleology and function. As noted in the introduction, throughout biology there's a common intuition that there's an ontological difference between the living world and the non-living world, and that understanding teleology is the key to discovering this ontological difference. While I could speculate about the various reasons one might have for holding such a commitment, it is important to remember that presently there is no definition for life. Some even suggest that searching for such a definition is fruitless endeavor (see e.g. Jabr, 2013). Furthermore, it seems important to remember the historical shift that took place as the notion of "life" changed during the 19th century. What could be deemed the precursor to today's organizational approach became dominant around this time. As Jacob observes, "throughout the seventeenth century and most of the eighteenth century the particular quality of organization called 'life' by the nineteenth century was unrecognized." (Jacob, 1970, p. 34) At earlier points in history, it was often the case that there wasn't as bright a line between the organisms and everything else. It was around the 19th century when the idea that the unique organization of *living* organisms took hold, and that was what made them more than just complex machines. The move away from mechanism in the 19th century introduced the idea that there was an ontological difference between the living and non-living worlds. Thus, it doesn't seem surprising, given the historical tension between mechanistic and teleological explanations (see Babcock and McShea, 2022), that the limitations of mechanistic approaches might tether ideas about teleology to organizational accounts as providing the avenue for understanding the apparent ontological difference. In the last section of this paper, I'll address this concern explicitly, arguing that such concerns are misplaced. But for now, let's examine whether Mossio and Bich's efforts to block the extension of their account to non-biological entities succeeds.

Mossio and Bich offer a nuanced assessment of whether teleology extends to inanimate nature. They begin by noting that the matter remains an open question in the literature: some argue that certain dissipative structures contribute to their own maintenance, while others argue against it. If it turns out that certain inanimate dissipative structures do contribute to their own maintenance, then such structures would be intrinsically teleological, and this would mean that teleology extends beyond biology. But they conclude with the caveat that such forms of inanimate teleology would be "a radically different kind of causal regime" than those found throughout biology (Mossio & Bich, 2017, p.1113). Inanimate dissipative structures would have "low internal complexity", they would "not realise closure" and they would be "largely determined by external boundary conditions." Thus, the causal regimes found throughout the biological world share almost none of the features found in these other kinds of dissipative structure other than being teleological. In essence, it would show that teleology comes in vastly different configurations. What does such a possibility entail for organizational accounts of teleology?

The possibility that dissipative structures could be teleological according to the organizational account lends support to what was established at the end of the previous section. Acknowledging that teleological systems can exist without realizing closure and have low internal complexity while being determined by *external* conditions is consistent with the premise that external fields are responsible for generating goal-directedness. These systems have lower degrees of teleology, but it seems to be teleology nonetheless. The "problem" that teleological systems are located outside self-maintaining organisms is not a problem when teleology is allowed to be externally driven, like when it results from things like gravitational fields. And, once we abandon the idea that teleology has special explanatory value when trying to understand living systems, this outcome is not surprising. That a hurricane only contains minimal self-maintaining properties, but is otherwise mostly directed by much larger scale geothermal and atmospheric fields, does not entail it's not teleological. The persistent and plastic behaviors of hurricanes, such as moving northwest from the Eastern Atlantic into various areas of North America, and developing when warm, moist air rises to create low pressure below it, then spinning in a counterclockwise direction (when in the northern hemisphere) shows they are teleological. That hurricanes are not alive is, then, only a problem for those seeking to understand the unique properties of living organisms. It is not a problem for those seeking to understand teleological systems. Where does this leave organizational accounts?

I remain agnostic about whether closed causal regimes exhibit unique teleological properties. It is certainly possible that particular kinds of teleological systems are only found in closed causal regimes. While organizational accounts identify many interesting features of self-maintaining systems, they do less in providing a theory of teleological systems. This is particularly true if teleological systems are found in areas of biology other than just in living systems, such as in evolutionary trends. Thus, it seems very possible that the organizational accounts will yield a path forward in understanding some of the unique qualities of living systems, however I'm doubtful that they reveal as much about teleology.

Another problem that the organizational accounts face is one raised in Garson (2016). Garson shows that organizational accounts of function[8] are subject to what he calls the "liberality objection". This objection is that the organizational account is too liberal because it ascribes functions in unintuitive ways. He points out that the account results in having to say that panic disorders are functional, because such disorders contribute to their own self-maintenance. Notice, this objection is similar to what has been discussed in this section. Mossio and Bich worry that their account of teleology is too liberal because it applies to certain non-living structures. As we've seen, this worry is not without cause. However, we've also seen that the field theory is able to absorb the problematic counterexamples that Nagel, Mossio and Bich attempt to address. It does this by showing that teleology comes in degrees that are relative to the persistence and plasticity the system exhibits.

Having considered an organizational account of teleology, let's now make the transition from teleology to function by turning to Garson's generalized selected effects account of function, or the "GSE" account. I want to look to the GSE account of function because Garson offers a very different approach to a very similar problem: How to avoid overextending one's account so that it doesn't include certain forms of inanimate nature?

5 Functions and eroding rocks

A counterexample that has been presented as a stumbling block for a GSE account of function is the case of rocks being eroded on a beach (see Lewens, 2004; Kingsbury, 2008; Garson, 2019; Bourrat, 2021). In its canonical form, the SE account holds that the function of x is to f if f has been selected in the past.[9] This account has a long history that originates with Wright (1973, 1976), though it has been refined by others, such as Neander (1991) and Millikan (1989). However, Garson's GSE account of function aims to extend the account further by incorporating instances of evolution by natural selection that take place without reproduction. While the account has many virtues, it is susceptible to be critiqued with a rock sorting example. When waves on a beach grind rocks into each other, a sorting process occurs. Harder rocks erode softer rocks, resulting in the selection of harder rocks over softer rocks. This seems to entail that hardness is a function of these rocks because these rocks have been selected for. But, like what we observed with the organizational accounts, this creates trouble for the GSE account if one wants to avoid the outcome that rocks have natural functions, i.e. that inanimate natural entities might have functions. This is

[8] The organizational account of function that Garson addresses is found in a series of papers that include Mossio et al. (2009); Saborido et al. (2011).

[9] In line with the points made about teleology and function in Sect. 2, I will treat the SE account loosely throughout this section, assuming that where there are functions, there are also teleological systems.

what leads Garson (2019) to attempt to delimit the scope of a GSE account. He argues that because rocks on a beach do not forms populations, selective processes cannot act on them. But before examining Garson's argument, let's consider why anyone would think this kind of rock sorting is an instance of natural selection to begin with.

Van Valen (1989) saw that selection has at least two modes of producing adaptations beyond reproduction. These other modes are *growth* and *persistence.* Differential persistence applies to the rock case because it measures fitness via the continued persistence of an entity. Harder rocks are fitter insofar as they persist longer than softer rocks. As Bourrat (2021) observes, some philosophers of biology and evolutionary biologists have directed attention to the importance of differential persistence and growth, or *multiplication*, in understanding evolutionary selective processes (e.g. Bouchard, 2008, 2014; Bourrat, 2014; Doolittle, 2014, 2016). These authors have presented a strong case for a much broader conception of natural selection, one that may well extend selective processes to things like certain kinds of rocks.[10]

To block the extension of GSE functions to rocks, Garson's strategy is to show that rocks do not form populations. Because the interactions between individual rocks are extremely limited, they fall short of having the type of interactions necessary to form populations. And, if rocks don't form populations, then they cannot be subjects of selective forces. However, recently Bourrat (2021) has indicated that, ultimately, Garson's effort to block the extension of GSE functions does not succeed.[11] He points out that there are numerous instances when natural selection acts on entities that are not parts of the same population, citing examples from Sober (1984), Brandon (1990) and Lewens (2004). These arguments cast doubt on whether being part of a population is necessary for selection to occur, and thereby whether functions can only be found in populations. To present just one of Bourrat's reasons: Darwin imagined two plants on the edge of a desert. If they were subjected to the selective force of a draught, they would not be in competition with each other, nor interacting in any way. In such a case, they do not form a population by any definition. Yet, like the rocks, they would be subject to selection in the form of differential persistence. Such cases lead Bourrat to "remain pessimistic" about whether there is a systematic means through which attributions of functions can be limited to biotic entities. In fact, Bourrat ends his paper quoting a long section from Van Valen (1989) where Van Valen extends evolution by natural selection to minerals.

Insofar as Bourrat is correct, it means that, like in the cases considered in the sections above, once again we're unable to find a principled way to restrict functions to only animate nature. Even more tellingly, Bourrat tentatively suggests that the more permissive application of function to certain parts of non-living nature might mean developing an account of function that comes in degrees. Thus, he suggests

[10] In spite of the attention that differential persistence and growth has recently received, one might deny that a process like rock sorting is a genuine instance of selection because rocks do not reproduce. In essence, it's not selection because it fails to meet necessary conditions for selection to occur, like those offered in Lewontin (1985) or Hull et al. (2001). If that is a worry, see Van Valen, Bouchard, Doolittle or Bourrat's work.

[11] Recently, Garson has offered a response to Bourrat in Garson (2022). There Garson notes that after a point, revising the meaning of a term, e.g. "function", ends up being so revisionary that it's unclear the same topic is being considered (see Garson, 2022, pp. 20 – 1).

something not unlike what Matthewson (2020) does and what I am suggesting in this paper. The idea that function comes in degrees aligns with what field theory has to say about the structure of teleology. If teleology extends to inanimate nature, it's not surprising that functions do too given the connection teleology and function have with each other. And on this count, field theory may have an explanatory edge over Matthewson's account because while Matthewson notes that natural selection comes in degrees, his argument does not explicitly consider the implications of multiplication. Thus, it isn't obviously able to take onboard the extension of selective processes to inanimate entities. Still, this shouldn't undermine the broader agreement that's coming into focus: functions and teleology come in degrees.

In the next section, I look to minerals as a case study to illustrate how functions and teleology extend to non-living entities. Following up on Van Valen's extension of such selection to minerals, mineralogists have already made a connection between selective forces and minerals. Looking at their assessment reveals that differential persistence and growth may, at times, yield fairly robust teleological systems and functions.

6 Mineral functions and teleology?

Relatively recently some mineralogists have hypothesized that mineral species have evolved. In a theory put forward in Hazen et al. (2008), the authors argue that mineral species exhibit some of the key aspects of evolving systems such as selection, punctuation, and extinction. Although they make no reference to Van Valen's modes of selection they point towards evidence in the geological record to support a view depicting minerals as species that change on a geological time scale. And while some philosophers have keenly noted that evolving systems exist beyond the scope of life, they have tended to think such evolving systems fall short of generating true teleology (see e.g. Brandon, 1981). In this section, I present a case for how the evolution of minerals shows that minerals are directed by McShea-style fields, through differential persistence and growth, to generate higher degrees of teleology and function than what we see in the rock sorting example above. Let's begin by reanalyzing the rock sorting case.

At first it seems that waves grinding and battering rocks into one another necessarily leads to the persistence of harder rocks over softer rocks. And, if this were true, it would result in fewer rock types and little or no increases in complexity. It would give way to relatively uninteresting functions. However, as a differential selection process erodes rocks, it's equally possible to imagine an *increase* in rock types. Contrary to how this example has been used in the literature, consider how beach erosion often unfolds. Harder rocks on a beach, tending to be denser, are drawn further down on the beach, leaving softer rocks higher. These harder rocks are then eroded against other harder rocks at lower points on the beach, and softer rocks erode against other softer rocks at higher points on the beach. The sorting process driven by the waves continues. Degrees of harder and softer rocks are sorted at different levels along the beach. And the longer the process continues, the more stratification will take place, and the more rock types will be generated. Though one might think "hardness" is the only function we find, notice this process also makes traits like being "less dense" functional for the rocks that are at higher points on the beach. Other traits might be functional as well, e.g. smoothness or roundness. And notice that, for McShea, the waves and gravity are fields that are driving the acquisition of these functions. Analogously, the external selective processes that drive mineral evolution have resulted in the increase of mineral species, rather than the decrease one might anticipate from multiplication. And the functions these species have vary greatly too. This is particularly the case when viewing multiplication at geological and cosmological timescales. Mineral evolution provides interesting cases of complex teleological and functional systems, where the number of mineral species has increased through other chemical and physical processes. And though these processes are somewhat different than the mechanical process of erosion, there are parallels between the two.

Of course, one might wonder why anyone would think that mineral species evolve. The first point the authors of the mineral evolution hypothesis use to support this idea is that punctuated equilibria, as presented in Eldredge and Gould (1972), are common in complex systems. And, on a geological timescale, minerals have undergone punctuated and irreversible events (they identify ten such events during the Earth's history). These ten events show that mineral species, far from being exemplars of a classic conception of static natural kinds with intrinsic essences, often undergo radical changes.[12] Another point addresses the question of extinction. In this case, they offer some evidence that could support the possibility of minerals going extinct. While most all of the Earth's mineral forming processes are "still in play", spare "those that formed the unusual reduced minerals of enstatite chondrites", there's no reason to think certain mineral species couldn't permanently disappear (Hazen et al., 2008, p.1713). They look to changes on other planets, like Venus, where minerals that were once present no longer exist given the planet's current high-temperature surface environment. In essence, just because the majority of mineral forming processes continue on Earth doesn't entail that they need to continue.[13] But, of course, what is most central to the question at hand, and what would also show that minerals evolve, is whether they are subjects of selective processes, as Van Valen thought.

On the question of selection Hazen et al. begin by clarifying that they are not arguing that mineral selection is the same as Darwinian natural selection. But when positioned alongside the case of rocks being sorted on a beach, the evolution of minerals presents a similar, though much larger scale instance where Van Valen's other modes of selection (persistence and growth) create functions. As the authors note, "the driving force for mineral evolution… is the evolving diversity of prebiotic and biologically mediated temperature-pressure-composition environments." (Hazen et al., 2008 p. 1712) Like the waves creating functions for the rocks on the beach, certain mineral species persist and grow as they are selected through various tempera-

[12] One might adopt a view of natural kinds, like the one put forward in Magnus (2012), which might allow for minerals to be natural kinds *and* undergo change. Though also see Santana (2019) for an interesting discussion of this question.

[13] Of course, one might respond to this claim, as Rosing (2008) does, by noting, "the concept of mineral evolution is unsatisfactory because, unlike living species, mineral species do not depend on the transfer of information. As a result, identical minerals will emerge on the mineralogical scene repeatedly, as long as the physical and chemical boundary conditions can be re-established."

ture-pressure-composition environments. This aligns with Van Valen's thinking. Van Valen suggests that quartz is selected over feldspar in certain environments because being harder turns out to be functional for the quartz. Perhaps a clearer example of a functional trait in quartz is the transition it makes from being trigonal to hexagonal at 573 °C (Raman & Nedungadi, 1940). That quartz alters its chemical structure to persist - which is to say remain as quartz - above 573 °C while other minerals breakdown in such high pressure-temperature environments, makes the transition from being trigonal to hexagonal functional for quartz. Minerals, then, provide a case where, following Bourrat's critique of Garson, ascribing GSE functions to mineral species is unavoidable. These modest forms of selection end up yielding some rather robust functions. In fact, we get a whole array of mineral species with different functions as a result of these different environments. Let's call a GSE account that does *not* restrict selection to populations the "expanded" GSE account.

An expanded GSE account shows that minerals do have certain functions. And, if the expanded GSE account of function works one might wonder what need is there for field theory? To see the need, recall that, following Wright, functions and teleology are *not* equivalent. Functions only arise in the context of larger teleological systems. Given this is the case, even with the expanded GSE account, we still need an account of the larger teleological system that's generating these functions. Field theory provides this account as it easily extends to the non-living natural world. Presenting an argument for the compatibility of an expanded GSE account with field theory is beyond the scope of this paper. Nevertheless, for the sake of argument, let's assume for the moment that the accounts can be rendered compatible. Assuming their compatibility, we can consider how field theory might go about locating teleology in mineral evolution. I will hazard some speculation about how the processes that have driven mineral evolution are deemed teleological in a field theoretic framework (leaving aside the possibility of a more thorough account for mineralogists.) I believe an example of a teleological system can be seen in what Hazen et al. identify as the Earth's first and second eras of mineral evolution. This brings us all the way back to the Earth's formation.[14]

The authors of mineral evolution begin their account with pre-stellar molecular clouds, because these are the starting points of denser objects, like protoplanets and stars. The gravitational pull of all the separate particles in one of these clouds eventually results in them all clumping together. That clump, in turn, creates an increasing gravitational pull that draws in more and more particles. These clumping particles contain the roughly dozen elemental chemical compounds from which all mineral species are derived. When these dozen minerals "clump" to form primitive planetesimals, an expansion of mineral species begins. The clumping creates the start of aqueous and thermal processes - processes that McShea would consider to be fields. The external liquid and heating processes end up, in essence, stratifying the initial mineral species to generate some ~ 250 further species from the initial dozen. These 250 species also happen to be the minerals that make up meteorites, showing the process is teleological. It exhibits persistence and plasticity. The clumping of pre-stellar

[14] And here it's worth noting that in his own analysis of goal directedness, Wright too suggests that a "lump of quartz" could be teleological. (Wright, 1976, p.59)

molecular clouds is persistent and plastic insofar as it repeatedly results in roughly the same “end state” that is an expansion of mineral species from the initial dozen to roughly the same 250 species of the thousands of different possible chemical configurations that could create other mineral species. And these 250 species are commonly found in the early stages of evolving chondrites (i.e. an early type of meteorite). No matter where the initial dozen mineral species that make up the cloud begin, nor how they might get knocked off-course during these early phases of gravitational clumping, they reliably lead to similar increases in the kinds and number of mineral species. And, of all the various possible chemical configurations that can form minerals, only a fraction of these have come together to form the roughly five thousand mineral species currently observed on Earth. So, while it is possible that the known mineral species are simply the result of stochastic processes, this suggests it’s more plausible to think that mineral species are guided by changes in large-scale, externally driven temperature-pressure-composition environments – i.e. fields. The mineral species that persist and grow when subjected to the environmental fields acquire functional traits that allow them to continue to persist and grow, leaving aside other possible mineral types unselected because they are less functional within this gravitational clumping.

There is not enough space to provide a full account and defense of how the other subsequent eras of the Earth’s mineral evolution might also be deemed teleological. As I said above, I leave such a task to mineralogists. However, my impression is that many of the selective processes that drive mineral evolution are generally persistent and plastic. To pick out just one other salient example: certain minerals, in rocks, will change in response to increasing temperatures (prograde metamorphism), but the rocks do not necessarily return to their original state when the temperature decreases (retrograde metamorphism). Such processes result in irreversible events that channel the direction of rock and mineral evolution. It might be surprising and counterintuitive to think about mere differential persistence and growth leading to a proliferation of mineral species, but given the historical way minerals are formed, the result actually isn’t surprising at all.

But let me be clear that I do *not* mean to imply that the selection processes – the fields – that drive mineral evolution are on a par with those that drive biological evolution. Obviously, the diversity of mineral species is nowhere near as complex as what we see in biological evolution. The expansion from twelve mineral species to the roughly 5,000 identified on the Earth today is, by many magnitudes, far less proliferation than what we find in biological evolution. Nevertheless, mineral evolution has generated a great deal of complexity. I believe observing this necessitates accepting that teleology and functions extend to non-living entities, and they do so to varying degrees.

7 Final thoughts and some possible objections

The presence of differential persistence and growth mean there are forms of natural selection that act on inanimate, natural entities that are best captured by field theory. I’ve argued that mineral evolution provides an example of how this type of selection gives rise to relatively complex functional and teleologically directed systems. Certain inanimate entities have the single "end" of persistence and growth in relation to the field(s) within which they are immersed. When selective forces can act directly on an entity, from above, so to speak, they sculpt in it such a way that it possesses functions and goals. This is what Bourrat and others have already gestured at, and what field theory provides an account for. It also shows the ascriptions of function and goal directedness exist on a spectrum that's relative to how much persistence and plasticity is observed in a system. A falling rock has very low persistence and plasticity. Rocks on a beach and balls in bowls exhibit a bit more. This results in their possessing higher degrees of teleology. Hurricanes, being more complex and having more persistence and plasticity, have even higher degrees. Mineral species are, perhaps, even more so, demonstrated by their surprisingly complex evolutionary trajectories. Acknowledging that there is a spectrum of teleology and function shows such systems are not unique to life. In fact, it may show that thinking about life in dichotomist terms offers an impoverished conceptual framework to deploy when trying to understand function and teleology generally.

There are, of course, objections that might be raised against dissolving a hard division between animate and inanimate nature, and by letting teleology and function creep into balls in bowls, minerals, and falling rocks. I believe one of the primary objections is that although field theory can provide a consistent account of how teleological systems work, it ends up being far too permissive an account. In naturalizing teleology, it extends the scope of teleology too far and, in doing so, it threatens to usher a return to something like a mechanistic view of the world where there's nothing special or unique to life that can't be found in a complex machine. If everything is simply governed by fields to predetermined ends, we're left with an account of teleology drained of all mystery. To conclude, I'll sketch a tentative response to such worries.

An objection along these lines is, from a certain point of view, merited. In naturalizing teleology and function, field theory in combination with an extended GSE account shows that the physical stuff (which includes fields) that makes up the world is all subject to, and directed by, upper level fields. It most certainly is a deflationary account as it suggests the difference between a falling rock and complex, human decision making is a matter of degree, not a difference in kind. However, such a conclusion needn't entail a return to a mechanistic world view, nor does it imply that differences in degree of complexity between a falling rock and a human decision aren't profound and astonishing. Instead, what the theory indicates is the key to understanding teleological and functional systems comes from the identification of fields. When it comes to falling rocks, balls in bowls, and even the evolution of minerals, various upper level fields *have* been identified. That's why these systems are less mysterious. The identification of these fields provides amazing explanatory value that allows us to understand these teleological systems. Locating the other external fields that direct more complex teleological systems is the best path forward in understanding these systems as well. It should not be surprising that when fields are correctly identified the teleological systems they create look a bit less mysterious, any more than it should be surprising when a single field's influence is able to give rise to interesting functions and goals.

Admittedly, one might worry that this robs life of some of its uniqueness. For example, that it robs the teleological capacities from something like the agency exhibited in human decision making. But accurately identifying fields doesn't threaten life of its special status, nor does it diminish the freedom inherent to teleological entities if one adopts a compatibilist position in the way suggested in Babcock and McShea (2022). In essence, even if my behaviors are wholly determined, and my wife might be able to predict them very accurately at times, neither of those facts would rob me of my free will. It only means that, at times, she understands the fields that both guide and determine my actions quite well. What directs and determines my persistent and plastic behaviors may be a little less mysterious to her than they are to someone who doesn't know me well. Our understanding of gravitational fields, at its root, is a similar phenomenon. Our understanding of gravity affords us so much explanatory power that it has rendered what used to be mysterious occurrences, like falling rocks, utterly comprehensible. That falling rocks no longer appear mysterious has been one of greatest advances in understanding teleology. It's been a mistake to think it proved falling rocks are not at all teleological.

Decoupling ideas about teleology from ideas about life is an important and necessary step in making progress in understanding both. The first bit of progress on this front is seeing that teleology and function come in degrees that are relative to the persistence and plasticity present in the system and such systems are found throughout many different physical mediums - both those that are living, those that are not, and everywhere in between.

Acknowledgements I would like to extend my thanks and gratitude to Monika Piotrowska, Pierrick Bourrat, the anonymous referees, and particularly to Dan McShea for their helpful feedback on earlier drafts of this paper.

Declarations

Competing interests I have no competing interests to disclose.

References

Ayala, F. J. (1998). Teleological explanations versus teleology. *History and Philosophy of the Life Sciences*, *20*, 41–50.

Babcock, G., & McShea, D. W. (2021). An externalist teleology. *Synthese*, *199*, 8755–8780. https://doi.org/10.1007/s11229-021-03181-w.

Babcock, G., & McShea, D. W. (2022). Resolving teleology's false dilemma. *Biological Journal of the Linnean Society*. https://doi.org/10.1093/biolinnean/blac058.

Bedau, M. (1991). Can biological teleology be naturalized? *The Journal of Philosophy*, *88*(11), 647–655. https://doi.org/10.5840/jphil1991881111.

Bedau, M. (1992). Goal-Directed Systems and the good. *The Monist*, *75*(1), 34–51. https://doi.org/10.5840/monist19927516.

Bouchard, F. (2008). Causal processes, fitness, and the differential persistence of lineages. *Philosophy of Science*, *75*, 560–570. https://doi.org/10.1086/594507.

Bouchard, F. (2014). Ecosystem evolution is about variation and persistence, not populations and reproduction. *Biological Theory*, *9*, 382–391. https://doi.org/10.1007/s13752-014-0171-1.

Bourrat, P. (2014). From survivors to replicators; evolution by natural selection revisited. *Biology and Philosophy*, *29*, 517–538. https://doi.org/10.1007/s10539-013-9383-1.
Bourrat, P. (2021). Function, persistence, and selection: generalizing the selected-effect account of function adequately. *Studies in History and Philosophy of Science*, *90*, 61–67. https://doi.org/10.1016/j.shpsa.2021.09.007.
Brandon, R. N. (1981). Biological Teleology: questions and explanations. Studies in the history and. *Philosophy of Science*, *12*(2), 91–105. https://doi.org/10.1016/0039-3681(81)90015-7.
Brandon, R. N. (1990). *Adaptation and environment*. Princeton University Press.
Cohen, S. M. (1994). Aristotle on Elemental Motion. *Phronesis*, *39*, 150–159.
Corning, P. A. (2019). Teleonomy and the proximate–ultimate distinction revisited. *Biological Journal of the Linnaean Society*, *127*(4), 912–916. https://doi.org/10.1093/biolinnean/blz087.
Dobzhansky, T., Ayala, F. J., Stebbins, G. L., & Valentine, J. W. (Eds.). (1977). *Evolution*. Freeman.
Doolittle, W. F. (2014). Natural selection through survival alone, and the possibility of Gaia. Biology and Philosophy, 29, 415–423. https://doi.org/10.1007/s10539-013-9384-0
Doolittle, W. F. (2016). Making the most of clade selection. *Philosophy of Science*, *84*(2), 275–295. https://doi.org/10.1086/690719.
Eldredge, N., & Gould, S. J. (1972). Punctuated equilibria: an alternative to phyletic gradualism. In T. J. M. Schopf (Ed.), *Models of Paleobiology* (pp. 82–115). Freeman, Cooper and Co.
Garson, J. (2008). Function and teleology. In A. Plutynski & S. Sarkar (Eds.), A companion to the philosophy of biology (pp. 525–549). Blackwell. https://doi.org/10.1002/9780470696590.ch28
Garson, J. (2016). *A critical overview of biological functions*. Springer International. Publishing. https://doi.org/10.1007/978-3-319-32020-5
Garson, J. (2017). A generalized selected effects theory of function. *Philosophy of Science*, *84*(3), 523–543. https://doi.org/10.1086/692146.
Garson, J. (2019). What biological functions are and why they matter. Cambridge University Press. https://doi.org/10.1017/9781108560764
Garson, J. (2022). Do transposable elements have functions of their very own? *Biology and Philosophy*, *37*(20), https://doi.org/10.1007/s10539-022-09855-0.
Goudge, T. A. (1961). *The ascent of life. A philosophical study of the theory of evolution*. University of Toronto Press.
Hazen, R., Papineau, D., Bleeker, W., Downs, R. T., Ferry, J. M., McCoy, T. J., Sverjensky, D. A., & Yang, H. (2008). Mineral evolution. *American Mineralogist*, *93*, 1693–1720. https://doi.org/10.2138/am.2008.2955.
Hull, D. L., Langman, R. E., & Glenn, S. S. (2001). A general account of selection: biology, immunology and behavior. *Behavioral and Brain Sciences*, *24*(3), 511–527. https://doi.org/10.1017/S0140525X01004162.
Jacob, F. (1970). *La logique du vivant. Une historie de l'hérédité. Paris: Gallimard* (Eng. Trans. By B. E. Spillmann, the Logic of Life). Pantheon Books.
Jabr, F. (2013). Why Life Does Not Really Exist, Scientific American, published 02 December 2013
Kingsbury, J. (2008). Learning and selection. *Biology and Philosophy*, *23*, 493–507. https://doi.org/10.1007/s10539-008-9113-2.
Lee, J. G., & McShea, D. W. (2020). Operationalizing goal directedness: An empirical route to advancing a philosophical discussion. Philosophy, Theory and Practice in Biology. https://doi.org/10.3998/ptpbio.16039257.0012.005.
Lewens, T. (2004). *Organisms and artifacts: design in nature and elsewhere*. MIT Press. https://doi.org/10.7551/mitpress/5172.001.0001.
Lewontin, R. C. (1985). Adaptation. In R. Levins, & R. C. Lewontin (Eds.), Dialectics and reductionism in ecology (pp. 65–84). Harvard University Press.
Magnus, P. D. (2012). *Scientific Enquiry and Natural Kinds: from planets to Mallards*. Palgrave MacMillan. https://doi.org/10.1057/9781137271259
Matthewson, J. (2020). Does proper function come in degrees? *Biology and Philosophy*, *35*(39), https://doi.org/10.1007/s10539-020-09758-y.
Mayr, E. (1988). The multiple meanings of teleological. In E. Mayr (Ed.), *Towards a new philosophy of biology* (pp. 38–66). Harvard University Press.
McMullin, E. (2002). The Origins of the Field Concept in Physics. *Physics in Perspective*, *4*, 13–39. https://doi.org/10.1007/s00016-002-8357-5.
McShea, D. W. (2012). Upper-directed systems: a new approach to teleology in biology. *Biology and Philosophy*, *27*, 663–684. https://doi.org/10.1007/s10539-012-9326-2.

McShea, D. W. (2016a). Hierarchy: the source of teleology in evolution. In N. Eldredge, et al. (Eds.), *Evolutionary theory: a hierarchical perspective* (pp. 86–102). University of Chicago Press.
McShea, D. W. (2016b). Freedom and purpose in biology. Studies in history and philosophy of Biological and. *Biomedical Sciences*, *58*, 64–72. https://doi.org/10.1016/j.shpsc.2015.12.002.
Millikan, R. G. (1989). In defense of proper functions. *Philosophy of Science*, *56*, 288–302. https://doi.org/10.1086/289488.
Monod, J. *Chance and necessity*. (A. Wainhouse, (1971). trans.). Alfred A. Knopf.
Mossio, M., Saborido, C., & Moreno, A. (2009). An organizational account of biological functions. *British Journal of Philosophy of Science*, *60*(4), 813–841. https://doi.org/10.1093/bjps/axp036.
Mossio, M., & Bich, L. (2017). What makes biological organization teleological? *Synthese*, *194*, 1089–1114. https://doi.org/10.1007/s11229-014-0594-z.
Nagel, E. (1979). *Teleology revisited and other essays in the philosophy and history of science*. Columbia University Press.
Neander, K. (1991). Functions as selected effects: the conceptual analyst's defense. *Philosophy of Science*, *58*(2), 168–184. https://doi.org/10.1086/289610.
Pittendrigh, C. S. (1958). Adaptation, natural selection, and behavior. In A. Roe, & G. G. Simpson (Eds.), *Behavior and evolution* (pp. 390–416). Yale University Press.
Raman, C. V., & Nedungadi, T. M. K. (1940). The α-β Transformation of Quartz. *Nature*, *145*, 147. https://doi.org/10.1038/145147a0.
Rosing, M. (2008). On the evolution of minerals, 456. *Nature*, 456–458. https://doi.org/10.1038/456456a.
Saborido, C., Mossio, M., & Moreno, A. (2011). Biological organization and cross-generation functions. *The British Journal for the Philosophy of Science*, *62*(3), 583–606. https://doi.org/10.1093/bjps/axq034.
Santana, C. (2019). Mineral misbehavior: why mineralogists don't deal in natural kinds. *Foundations of Chemistry*, *21*, 333–343. https://doi.org/10.1007/s10698-019-09338-3.
Sober, E. (1984). *The nature of selection*. MIT Press.
Toepfer, G. (2012). Teleology and its constitutive role for biology as the science of organized systems in nature. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *43*(1), 113–119. https://doi.org/10.1016/j.shpsc.2011.05.010.
Vane-Wright, R. I. (2022). Turning biology to life: some reflections. *Biological Journal of the Linnean Society*. https://doi.org/10.1093/biolinnean/blac141. blac141.
Van Valen, L. M. (1989). Three paradigms of evolution. *Evolutionary Theory*, *9*, 1–17.
Wright, L. (1973). Functions. *The Philosophical Review*, *82*, 139–168.
Wright, L. (1976). *Teleological explanations: an etiological analysis of goals and functions*. University of California Press.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.