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Goal Directedness and the Field Concept

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Abstract

A long-standing problem in understanding goal-directed systems has been the insufficiency of mechanistic explanations to make sense of them. This article offers a solution to this problem. It begins by observing the limitations of mechanistic decompositions when it comes to understanding physical fields. We argue that introducing the field concept, as it has been developed in *field theory*, alongside mechanisms is able to provide an account of goal directedness in the sciences.

1. Introduction

A new approach to goal directedness has been advanced in a series of papers by McShea and others (McShea 2012, 2013, 2016a, 2016b, 2023; Lee and McShea 2020; Babcock and McShea 2021, 2023; Babcock 2023). At the heart of that approach is the concept of a field. Field theory (FT), as the approach is called, argues that the purposeful behavior of goal-directed entities is accounted for by fields, relegating mechanism to a subordinate—although still critical—role. However, so far, in work on FT, the concept of a field is underdeveloped. This article remedies this underdevelopment by offering an account of the relationship between fields and mechanisms.

In addition to providing an account of fields and their relationship to mechanisms, we also defend the view against other criticisms that might arise from introducing fields into the prevailing mechanistic ontology. The field theoretic view argues that the field concept applies across disparate domains, spanning hierarchical systems from the atomic to the astrophysical, and that it therefore has an extraordinary range of application. This seems to open the theory up to a charge of overbreadth (see Garson 2016). Therefore, another aim in the article is to show how the explanatory advantages that come with FT outweigh the disadvantages that might come with a permissive concept of a field. Importantly, our aim is not to offer a defense of a particular view of fields to the exclusion of others. Nor is it a defense of FT generally. Rather, it is a further development of FT, in which fields play a central role, showing one way that fields can be understood. The potential payoff is the

recognition of an architectural commonality that links all goal-directed systems (see McShea 2012; Lee and McShea 2020; and Babcock and McShea 2021, 2023).

We begin with a brief outline of FT, showing how the field concept is used in the theory. Second, we show how the notion of a field is relational. Whether a structure constitutes a field depends on the particular levels of hierarchical organization being examined. This entails that fields are multiply realizable. Third, we contrast the field concept with purely mechanistic explanations, illustrating that introducing fields into a mechanistic ontology is necessary to capture certain types of causal relations. In particular, the field concept makes it possible to account for teleological phenomena by recognizing the “within” relation, which is not available to purely mechanistic explanations.

2. A theory of goal directedness and the role of fields

FT argues that goal-directed phenomena are explained by a certain relational quality, between what are called “upper-level fields” and the teleological entities within them. According to the theory, the hallmarks of teleological behavior, identified by Sommerhoff (1950) and Nagel (1979), are persistence and plasticity. Persistence is returning to a trajectory toward a goal following deviations, and plasticity is finding a goal-directed trajectory from a variety of starting points. FT argues that these behaviors arise from immersion within a field. When an entity seeks an end, or moves toward a target trajectory, it is because there is an external field directing it toward that end or trajectory. For example, sea turtles find their natal beach by tracking the earth’s magnetic field. The nature of the field and its role in guiding a turtle is easy to appreciate, as is the “insiderness” relationship that makes the turtle’s persistence and plasticity possible: The field is external, large, and immersive. No matter where the turtle starts, and no matter it wanders, the field is there to direct it to the right trajectory. Less straightforward are cases in which the field is composed of physical materials not ordinarily associated with fields. Under FT, in embryonic development, a gene-expression gradient is a morphogenetic field that directs the persistent and plastic behavior of cells within it. FT is intended to capture these kinds of diverse, goal-directed behaviors in a single, unifying explanatory framework.

Given the key role the field concept plays in FT, a natural question is how do the fields in FT compare to more traditional conceptions of fields in the sciences, as they emerged from the work of people like Newton, Faraday, and Maxwell? In FT, fields are physical, and many in physics have understood them that way too. Newton, for example, understood gravitational fields as physical, struggling with the problem of how they could work without a physical medium. Today in physics, the ontological status of fields is still debated. Nevertheless, fields play an indispensable explanatory role, both operationally and theoretically, in our best science.

Despite the rich history of fields in physics (McMullin 2002), FT draws its inspiration from elsewhere, from field concepts in developmental biology (e.g., Waddington 1957; Wiess 1969) and systems theory. The best modern characterization of a field in FT we have found comes from Levin (2012), who describes fields as structures with “nonlocalized influence” over the points contained within them. He shows through various experiments that certain aspects of biological development must be governed by fields rather than by internal mechanisms, like genes. For example, after cutting the head and tail off a flatworm, bioelectrical manipulation of the remaining body can cause the animal to regenerate with two heads, one at each

end. And in repeated croppings of the head and tail, the animal always regenerates a two-headed form. A permanent change has been effected, and that is a change to a bioelectrical field within the organism, one that governs large-scale structure and arises without any alteration of the genes. More generally, Levin argues global positional information in the body arises from fields. McShea's (2012) insight arises from noting that fields, such as those described by Levin, account for the signature features identified by Nagel and Sommerhoff in teleological systems generally: persistence and plasticity. Returning to the turtle seeking its natal beach, the various mechanisms inside its brain are critical, of course, just as genes are in the regenerating flatworm, but in both cases, it is an external field that gives the guidance, that provides the global (literally, in the case of the turtle) positioning information.

The McShea–Levin view of fields has two consequences for FT's account of goal directedness. The first is that goal directedness always has an external origin given that fields are spatially external to the entities they direct (Babcock and McShea 2021). This stands in contrast to alternative accounts of goal directedness, agency, and teleology that argue for internalist or intrinsic accounts (e.g., Nagel 1979; Mossio and Bich 2017). (Importantly, however, as Babcock and McShea have pointed out, the claim of FT is not that fields must be external to the organism, only that they are external to the guided entity. When the guided entity is a small part within the organism - such as a tissue or group of cells - the guiding field - such as a hormonal field or a gene activation field - can be external to the part but still inside the organism.) The second is that goal directedness is a phenomenon that is only understood in the context of multilevel hierarchies, with fields occupying an "upper level" above the entities they direct (McShea 2012).

A full introduction to FT isn't possible here, so instead we offer an abbreviated primer. For details, see McShea (2012, 2016a) and Babcock and McShea (2021, 2023).

- 1) A field can direct changes in an entity's state or location. In development, morphogenetic fields can direct both a cell's movement and the pattern of genes it expresses. As random deviations in gene expression change a cell's behavior or physiology, the morphogenetic field is there to direct it back to the proper trajectory. Also, by virtue of its large spatial extent, a morphogenetic field can direct many cells at once.
- 2) The mechanisms within a goal-directed entity play a crucial role in its performance, but it is always and only the field that directs. For the turtle seeking its natal beach, the field is the *only* source of information about the target trajectory toward the beach.
- 3) In goal-directed systems, field direct from above but there are also lateral or nonhierarchical causes acting, accounting for deviations in an entity's behavior. A perturbation in a cell's physiology that causes it to depart temporarily from its goal-directed trajectory is a lateral cause.
- 4) Goal directedness comes in degrees. Turtle homing and flatworm regeneration involve goal directedness in places we expect to find it: complex organisms. But under FT, a ball in a bowl, rolling persistently and plastically toward the bottom, counts as goal directed too. This might sound counterintuitive, but field theory allows for degrees of goal directedness. The ball in the bowl counts as only minimally goal directed, owing to its extreme simplicity.

- 5) The fields described in FT can be simple or complex. The earth's magnetic field is simple. In contrast, morphogenetic fields can consist of multiple molecular species, arrayed in overlapping spatial patterns, directing cell trajectories and physiology in complex ways.
- 6) Fields can be penetrable or solid. The earth's magnetic field is penetrable, allowing goal-directed entities like turtles unobstructed passage. Or fields can be solid, like the solid sloping bank of a lake, that directs rainfall along the banks persistently and plastically back into the lake.

3. Physical and relational fields

Having explicated the general account presented in current work on FT, we are now in a position to articulate the common features of fields posited in FT. The first observation is that fields are understood relationally. This relational view arises from the general logic of hierarchy theory as has been deployed in the work of, for example, Feibleman (1954), Campbell (1958), Simon (1962), Salthe (1985), Wimsatt (1974, 1994, 2007), or Craver (2007). The throughline in these theories is that various phenomena are best explained as multilevel hierarchies. Multilevel hierarchies consist of nested systems, where entities are contained within larger entities, often arranged in a cascade of telescoping levels. This nesting is found in a vast range of different systems, from the chemical and biological to the psychological and social, even to the astrophysical.

Importantly, FT adopts what Salthe (1985) calls a triadic view of a hierarchy. When examining some goal-directed phenomenon, an intermediate or focal level is automatically picked out. The focal level is where a teleological entity is located. Mechanisms exist at the level below the focal level (discussed later) and upper-level fields exist at the level above. Restricting one's view to three "slices" of a nested hierarchy is key in FT because attempting to take into account the entire telescoping hierarchy in which every entity is embedded, from quarks below to the whole universe above, is conceptually unwieldy. Second, as Wimsatt has pointed out (1994), in the more interesting nested systems, including organisms, the most important causes acting on a focal entity typically lie at adjacent hierarchical levels. A given entity is most affected by its context, a field, at the level above or not far above it, and by its mechanism at the level just below or not far below. The precise level for both field and mechanism depends on the causal structure of the system, so that the levels deployed in the triad need to be picked carefully. In sum, under FT, the goal-directed entity lies at the focal level, the field that directs the entity lies at a level above, and the mechanism that passively facilitates the guidance provided by the field, or in more complex cases might actively effectuate it, lies at a level below.

It is in relation to upper and lower levels in the triad that a focal entity takes on its role. Thus, one and the same structure performs the role of a field at one level, while at another level it takes on the role of mechanism. At the heart of this view is what is commonly referred to as *context dependence*. For example, a given sequence of DNA only counts as a gene in relation to where it is located in the hierarchy. It must be in a particular position in a chromosome to play a hereditary role as a "gene." In a different location, the same sequence of nucleotides might be a different gene and may play no hereditary role. The argument regarding the role of genes in organismal

development presented in Babcock and McShea (2021) follows this principle. There they argue that morphogenetic fields are responsible for providing developmental direction to a tissue, and with respect to that tissue, the role of a cell within that tissue is mechanistic. Moving hierarchically downward, the cell takes on the role of a field that guides the parts contained within it, perhaps its organelles, and with respect to that field the role of the organelle components, such as molecules, including the genes, is mechanistic. In this account, a cell's role as a field or mechanism depends on whether one is looking down at the cells parts (with respect to which the cell is a field) or up at the morphogenetic field (with respect to which the cell is part of a mechanism). Thus, the status of a given structure as a field does not depend on it having any particular set of physical properties, but rather on its hierarchical context. A field is a field in FT only *with respect* to the level below.¹

In a triadic view, a wide range of structures can occupy the upper level with respect to any given entity. And under FT, all that are able to act causally in a consistent way on the entity count as fields, from the chemical and physical gradients that guide plant and animal tropisms, to gradients in development, to the GPS fields emanating from satellites and cell phone towers, to social and political fields and even to the wants and intentions that guide behavior. This is the sense in which in FT is permissive, designating as a field any physically extended structure that stands in a hierarchical causal relationship to a contained entity. But we would point out that while the permissiveness of the field concept might appear to be a weakness for FT, it seems its permissiveness is no greater than the permissiveness of the concept of a mechanism.

The relational quality of fields also reveals that they are multiply realizable in the standard sense (see e.g., Fodor 1974; Kitcher 1984). Any attempt to reduce the field concept to a singular physical description is bound to fail. A morphogenetic field is physically describable in terms of its molecular components and their distribution. An advertising field is a physical field describable in term of the physical activity of the electronic advertising media that constitute it. But the larger-scale effects of these fields can never be explanatorily reduced to their physical components. There is nothing metaphysically suspect about this combination of abstractness and physicality. Indeed, most of hierarchy theory, and systems theory generally, is built on it.

4. Mechanisms, fields, and the “within” relation

This section turns to features of FT that, while currently somewhat undeveloped, reveal the power of the field concept: the relationship between fields and mechanisms. More specifically, it is the relationship between FT and the contemporary accounts of mechanisms from what are sometimes called the “new mechanists.” At the onset, let's be clear that FT does *not* reject an ontology that includes mechanisms (see Babcock and McShea 2021). As discussed in section 3, FT argues that mechanisms exist at the level below the focal level, below the level of the goal-directed entity. And notice that introducing fields into an ontology alongside

¹ Wimsatt (1974) points out that hierarchical structure is often partial and boundaries are often not cleanly identifiable, especially in complex systems like organisms, but the structural noisiness of biological structure merely complicates the hierarchical analysis, without undermining it.

mechanisms is what makes the triadic view possible. The aim of this section, then, is to demonstrate how an ontology that includes fields alongside mechanisms offers explanatory resources that an ontology comprised solely of mechanisms cannot. To see why, we first need a rough outline of mechanistic theories.

Craver (2007) offers one of the clearest distillations of a contemporary account of mechanisms. Craver defines mechanisms as “a set of entities and activities organized such that they exhibit the phenomenon to be explained” (ibid., ch. 1). In this view, to explain the phenomenon that consists of S’s activity of Ψ ing, requires deferring to the mechanisms that exist at a lower level. S’s Ψ ing consists of entities at a lower level engaged in activities, that is X’s Φ ing. New mechanists, like Craver, take such an explanation to not “merely accommodate” what is found in various areas of the special sciences, such as neuroscience, but to “reflect” how such systems work (ibid., 2).

Mechanisms are, clearly, explanatorily useful, but they have limitations. The first limitation is that mechanists focus on only two levels. Because of this, a mechanistic explanation of S’s *goal-directed* activity only looks downward to X’s activities at a level below the goal-directed phenomenon. In contrast, FT’s triadic view looks to both a level below *and* a level above the phenomenon. At the level above there’s a field, call it “Z.” FT argues that Z accounts for S’s goal-directed activity. The reason FT argues for this is clear from Levin’s work. In the directed development of, say, a tissue (S’s Ψ ing), lower-level genes (X’s Ψ ing) do not fully account for the goal directedness of a given development sequence. The nonlocal, bioelectric field at the level above (Z) is required for a complete explanation. And, as has been argued in FT, this point applies to goal-directed phenomena at different hierarchical levels (e.g., at the level of organisms, collectives, or higher).

The second limitation for mechanisms is one Glennan (1996) observes. Glennan notes that certain phenomena, like electromagnetic fields, resist mechanistic modeling. This is because an electromagnetic field (EM field) cannot be meaningfully decomposed into parts, as “it is not possible to alter the electromagnetic field at a single point” (ibid., 54). In other words, if the phenomenon we want to explain is the action of an EM field (i.e., S’s Ψ ing), there are no mechanisms because there are no parts of an EM field Φ ing at a lower level. Likewise for Levin’s bioelectric fields. To this we would add that even where fields do have parts—such as morphogenetic gradients that can be decomposed into the molecular parts that make up the gradient—such decompositions take a reductionist stance that ignores how, *individually*, none of those parts provide any global information. They only do so collectively, as a field. Again, we stress that FT is not antimechanistic. There are some discordances between FT and certain mechanistic accounts (e.g., FT allows interlevel causation while Craver does not), but FT absolutely requires lower-level mechanisms. Our point is that mechanistic explanations have limitations: When there’s nothing to be found at a lower level that can account for an upper-level phenomenon, mechanisms reach their explanatory limits. FT offers a way to overcome those limits.

We’ll now consider the celestial navigation of dung beetles (Dacke et al. 2013) as a case that illustrates how mechanistic accounts have trouble explaining goal-directed phenomena. When a dung beetle acquires an orb of dung, it moves away from the dung pile to escape other beetles that might steal it. In doing so, it needs to escape the pile without circling back to it accidentally; in other words, it needs to move in a goal-

directed way (where the goal is “away from the dung pile”). In some clever experiments, researchers have demonstrated that the beetles orient using the Milky Way galaxy. When researchers blocked the beetles’ view of the night sky by mounting shields on their heads, the beetles became disoriented, whereas beetles that had the Milky Way in view followed straight lines away from the pile. A purely mechanistic model of such behavior looks only to the parts, to the inner workings of a beetle: its neural and motor systems. And such a mechanistic account has only two hierarchical levels, the beetle and those lower-level systems. But clearly, without an ontology that includes upper-level fields, mechanistic explanations have a blind spot. They leave out the structure that is providing the guidance, the structure that the beetle is “within”: the Milky Way. And it is this “withiness” that allows the beetle to move about in space while still retaining access to the guidance it needs, though it is not a mechanistic part of the Milky Way. A mechanistic framework doesn’t account for this very common “withiness” relation. FT, however, taking a triadic view, includes the higher level in its explanatory scheme. A dung beetle is contained *within* the upper-level field that is the Milky Way, and below the beetle are lower level mechanisms, including its neural and motor systems.

The “within” relation reveals important qualities of the field concept in FT: (1) Fields are necessary but not sufficient for goal directedness. Dung beetles are guided by the Milky Way, however, many (most) entities contained within the Milky Way are *not* directed by it. Thus, fields exist independently of, and are not predicated on, the presence of a goal-directed system. Similarly, magnetic fields exist even when there is no piece of iron upon which the field is exerting any force. (2) Identifying the upper-level fields responsible for a goal-directed phenomenon can be difficult, but understanding the system is otherwise impossible. For studies of animal navigation, like the dung beetle, fields are often revealed only after considerable empirical work. One of the key benefits FT offers to scientific practice is the general principle that when goal-directed behavior is observed, identifying the external, nonlocal field is a critical first step.

5. Unintuitive fields

To strengthen the account of fields provided, we would like to analyze cases that are not as friendly to our position. We have chosen what appears to be an especially difficult case for FT, a case that we imagine will engender skepticism of the field concept. The point is to reveal the versatility of the field notion, as well as to further explicate and narrow it.

In cases like the turtle and the dung beetle, the external field is (now) clear, the earth’s magnetic field and the Milky Way galaxy, respectively. However, guiding fields are not always so clear and it would be a mistake to believe that fields are always salient. Consider the migration of caribou herds. At a coarse grain, caribou are directed by the seasons, by the climate, which can be construed as a large immersive field. But in a finer-grained analysis, it turns out they are responding not as much to weather, but to a weather-dependent phenomenon—the prevalence of mosquitoes. So, caribou migration is goal directed, but it is often driven by tiny insects that do not seem to be good candidates for being fields because mosquitoes are smaller than caribou. Moreover, it seems there is nothing more than local interactions taking place between particular insects and particular caribou. Further, there is spatial

discontinuity among individual mosquitoes, and the boundaries of swarm might appear too ill-defined to consider it an upper-level structure of any kind.

A criticism along lines fails to appreciate the scale of the mosquito populations in the arctic. Research indicates the total biomass of mosquito populations in the Alaskan arctic to be roughly 96 million pounds during the period in the summer when *Aedes nigripes* reach their peak. The density of the insects is high enough that they are estimated to consume up to 300 milliliters of blood from an individual caribou per day. At this scale, a population of mosquitoes behaves like a chemical gradient, directing a caribou herd toward lower concentration, like a morphogenetic gradient directs cells and tissues in development. So long as the density of mosquitoes is consistent, the directional influence they have on the herd is the same: The herd will trend toward areas in the gradient that are less dense. Finally, a caribou herd lies within the spatial frame of the mosquito population and thus the population exists at a level above the herd. So, it's not individual mosquitos that caribou respond to but rather a population of them. And a mosquito population meets the conditions of a field insofar as: (1) the mosquito population is physical; (2) the population is large and immersive, with respect to a caribou herd, and therefore lies at an upper level with respect to it; (3) a caribou herd lies within the mosquito population; and (4) the population exists and exerts its causal influence nonlocally. It's a field, a "mosquito field."

The mosquito-caribou example is a special case in a much larger category of goal-directed systems in which the directing field is ecological. In these, the goal-directed behavior is not just the tropisms of individual organisms or groups but also the movement of and changes in lineages on an intergenerational timescale, in other words, evolution (McShea 2016a, 2023). In most of these latter cases, the directing ecological field is truly enormous, and—unlike the caribou example—the fields are multidimensional, consisting of great webs of physical and biological factors, extended in space and time, and complexly interacting to direct contained organisms and lineages. All meet the criteria we have set out for fields. Fields need not be simple, readily identifiable, nor conform to preconceived expectations. It is worth adding that the conceptual shift that FT is advocating in introducing an ontology that includes fields has parallels, we believe, with the slow embrace of mechanistic thinking that resulted in many advances in our understanding of biology.

6. Conclusion

So, what is a field in FT? To summarize the key points made in the preceding text: In the conceptual schema of FT, fields are (1) physical, (2) multiply realized, (3) relational at an upper level, in that they are immersive, containing, making a "within" relation possible because they (4) contain other entities which are not mechanistic parts of the field. As a result, fields are able to (5) act causally on at least some contained entities, which means (6) they can play a special explanatory role.

Goal directedness has famously, and for centuries, resisted mechanistic modeling (Kant 1790). Even more generally, goal-directed systems resist scientific modeling. Darwin is said to have solved the problem of how certain kinds of teleological entities arise (by natural selection), but his theory did nothing to explain how they work, how they are able to perform the seemingly impossible feat of pursuing future

outcomes: goals. FT offers a possible solution. The riddle in time is solved by extension in space, by the existence of fields of broad extent, so that wherever a goal-directed entity wanders, the field is there to direct it back to a trajectory toward its target. Mechanism has a critical role, but it is not the role usually imagined. Buried inside goal-directed entities, mechanism alone is blind, with no guideposts to lead it toward a goal. Rather, it is the external field that leads and guides.

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References

- Babcock, Gunnar. 2023. “Teleology and Function in Non-living Nature.” *Synthese* 201:4. <https://doi.org/10.1007/s11229-023-04099-1>
- Babcock, Gunnar, and Daniel W. McShea. 2021. “An Externalist Teleology.” *Synthese* 199:8755–80. <https://doi.org/10.1007/s11229-021-03181-w>
- Babcock, Gunnar, and Daniel W. McShea. 2023. “Resolving Teleology’s False Dilemma.” *Biological Journal of the Linnean Society* 39 (4):415–32. <https://doi.org/10.1093/biolinnean/blac058>
- Campbell, Donald T. 1958. “Common Fate, Similarity, and Other Indices of the Status of Aggregates of Persons as Social Entities.” *Behavioral Sciences* 3(1):14–25.
- Craver, Carl F. 2007. *Explaining the Brain: Mechanisms and the Mosaic Unity of Neuroscience*. Oxford: Clarendon Press; New York.
- Dacke, Marie, Emily Baird, Marcus Byrne, Clarke H. Scholtz, and Eric J. Warrant. 2013. “Dung Beetles Use the Milky Way for Orientation.” *Current Biology* 23 (4): 298–300. <https://doi.org/10.1016/j.cub.2012.12.034>
- Feibleman, James K. 1954. “Theory of Integrative Levels.” *British Society for the Philosophy of Science* 5 (17):59–66.
- Fodor, Jerry. 1974. “Special Sciences (or: the Disunity of Science as a Working Hypothesis).” *Synthese* 28 (2):97–115.
- Garson, Justin. 2016. *A Critical Overview of Biological Functions*. Dordrecht: Springer.
- Glennan, Stuart. 1996. “Mechanisms and the Nature of Causation.” *Erkenntnis* 44:49–71.
- Kant, Immanuel. 1790 [2005]. *The Critique of Judgment*. Cambridge: Cambridge University Press.
- Kitcher, Philip. 1984. “1953 and All That: A Tale of Two Sciences.” *Philosophical Review* 93 (3):335–73.
- Lee, Jong Gwan, and Daniel W. McShea. 2020. “Operationalizing Goal Directedness: An Empirical Route to Advancing a Philosophical Discussion.” *Philosophy, Theory and Practice in Biology* 12 (005). <https://doi.org/10.3998/ptpbio.16039257.0012.005>
- Levin, Michael. 2012. “Morphogenetic Fields in Embryogenesis, Regeneration, and Cancer: Non-local Control of Complex Patterning.” *BioSystems* 109 (3):243–61. <https://doi.org/10.1016/j.biosystems.2012.04.005>
- McMullin, Ernan. 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, Daniel W. 2013. “Machine Wanting.” *Studies in the History and Philosophy of Biological and Biomedical Sciences* 44 (4):679–87.
- McShea, Daniel W. 2012. “Upper-Directed Systems: A New Approach to Teleology in Biology.” *Biology and Philosophy* 27:663–84. <https://doi.org/10.1007/s10539-012-9326-2>
- McShea, Daniel W. 2016a. “Hierarchy: The Source of Teleology in Evolution.” In *Evolutionary Theory: A Hierarchical Perspective*, edited by N. Eldredge et al., 86–102. Chicago: University of Chicago Press.
- McShea, Daniel 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>
- McShea, Daniel W. 2023. “Evolutionary Trends and Goal Directedness.” *Synthese* 201:178. <https://doi.org/10.1007/s11229-023-04164-9>

- Mossio, Matteo, and Leonardo Bich. 2017. "What Makes Biological Organization Teleological?" *Synthese* 194:1089–1114. <https://doi.org/10.1007/s11229-014-0594-z>
- Nagel, Ernest. 1979. *Teleology Revisited and Other Essays in the Philosophy and History of Science*. New York: Columbia University Press.
- Salthe, Stanley N. 1985. *Evolving Hierarchical Systems*. New York: Columbia University Press.
- Simon, Herbert A. 1962. "The Architecture of Complexity." *Proceedings of the American Philosophical Society* 106:467–82.
- Sommerhoff, Gerd. 1950. *Analytical Biology*. London: Oxford University Press.
- Waddington, Conrad H. 1957. *The Strategy of the Genes*. London: George Allen and Unwin.
- Weiss, Paul A. 1969. "The Living System: Determinism Stratified." *Studium Generale* 22:361–400.
- Wimsatt, William C. 1974. "Complexity and Organization." In *Philosophy of Science Association 1972*, edited by K. F. Schaffner and R. S. Cohen, 67–86. Dordrecht: D. Reidel.
- Wimsatt, William C. 1994. "The Ontology of Complex Systems: Levels of Organization, Perspectives, and Causal Thickets." *Canadian Journal of Philosophy* 20 (Suppl.):207–74.
- Wimsatt, William C. 2007. *Re-engineering Philosophy for Limited Beings: Piecewise Approximations to Reality*. Cambridge, MA: Harvard University Press.