Enactive Mechanistic Explanation of Social Cognition

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Abstract

In this paper we examine an enactive approach to social cognition, a species of radical embodied cognition typically proposed as an alternative to traditional cognitive science. According to enactivists, social cognition is best explained by reference to the social unit rather than the individuals that participate in it. We identify a methodological problem in this approach, namely a lack of clarity with respect to the model of explanation it adopts. We review two complaints about a mechanistic explanatory framework, popular in traditional cognitive science, that prevent enactivists from embracing it. We argue that these complaints are unfounded and propose a conceptual model of enactive mechanistic explanation of social cognition.

Keywords: enactivism; social cognition; mechanistic explanation

Introduction

Embodied Cognition (EC) is most generally a plea to acknowledge that the states of the body and the environment can influence cognition and that lower sensorimotor knowledge plays a role in higher cognition like language and reasoning (e.g. Eerland, Guadalupe, & Zwaan, 2011). Radical Embodied Cognition (REC) is the claim that the body and the environment are actually part of cognition and as a result, for example, there is no need to have internal representations of the environment (Wilson & Golonka, 2013; van Dijk, Kerkhofs, van Rooij, & Haselager, 2008). Enactivism is a strand of REC that stems from the early work in philosophy of biology of Maturana and Varela (1980) and was popularized as an alternative to traditional cognitive science by Varela, Thompson, and Rosch (1991). It shares theoretical commitments with complex systems theory, phenomenology and Buddhist tradition in, on the one hand, grounding cognition on the organizational principles of living systems while at the same time giving a prominent role to the investigation of human experience. Three main principles adopted by enactivism are (1) challenging the dichotomy between internal components of the system and its external conditions, instead stressing the interaction between the two, (2) emphasizing emergent properties on higher levels of organization and (3) viewing the organism as an active autonomous entity that is able to adaptively maintain itself in the environment[1].

We think enactivism has a lot to offer to the study of cognition because it is an approach that is both naturalistic and non-reductionist. However, in this paper we highlight its methodological weakness that might be preventing it from gaining popularity, namely a lack of explicit commitment to how cognitive phenomena are to be explained. We exemplify this issue using a case of enactive accounts of social cognition. We further point out that contemporary cognitive science has two major explanatory frameworks on offer: a deductive-nomological framework, typically associated with REC, and a mechanistic framework, typically adopted by traditional cognitive scientists. We suggest that given the similarity between enactivists and other REC-ers, it is likely that enactivists implicitly subscribe to the deductive-nomological framework. In contrast to this, we argue that the mechanistic framework is not only compatible with enactivism but also preferable. We consider two main objections raised by REC-ers against mechanistic explanation and show that they rely on a misunderstanding of what such an explanation entails. We end the paper with a preliminary picture of enactive mechanistic explanation of social cognition.

Enactive Social Cognition

In broadest terms, a non-EC view on social cognition assumes that humans can interact with others successfully only if they are able to see other people as beings with mental states, can infer these states using a so-called 'theory of mind' or simulation and plug in the results of such inferences in planning their own actions. A regular EC view denies the need for such complex representations and inferences emphasizing real-time interaction with other people and perceptual information available in such settings. Certain varieties of simulation accounts of mindreading fit into this framework.

What distinguishes a REC approach is an insistence that the particular dynamics of social interaction themselves play a crucial role in explaining social cognition. This is because "becoming a temporary unit of social action with another person also involves creation of a new perception-action system with new capabilities " (Marsh, Johnston, Richardson, & Schmidt, 2009, p. 1219). Theoretically this has lead to a claim that there is no need to represent other people or their perspective on the world in order to coordinate with them successfully. Methodologically, it has been suggested that the correct level of analysis in the study of social cognition is the social unit, rather than an exclusive focus on the individuals that comprise it. Instead of searching for internal properties

[1] For an accessible introduction to enactivism see (McGee, 2005).

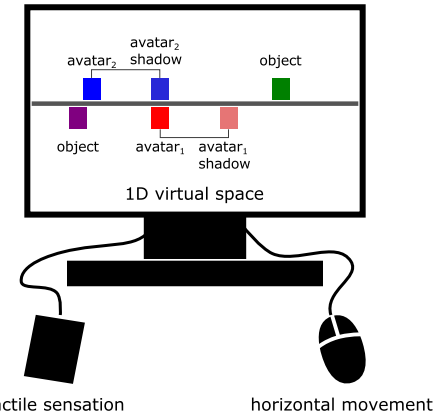

Figure 1: Perceptual crossing experiment.
A pair of blind-folded participants (call them A and B) are asked to interact in a one-dimensional horizontal field in which they can move using a computer mouse. The field is perceived solely via tactile feedback: encountering a stimulus produces a vibration. Participant A can sense 3 kinds of stimuli: a static object, B's avatar and B's "shadow" that follows B's avatar movement but does not provide B with sensation (the situation is analogous for B). Participants are asked to click when they think to be in contact with the other's avatar. A typical strategy is to move back and forth, especially when a stimulus is encountered. This allows for discriminating between a static and mobile object (if the stimulation changes despite the participant staying in place, the object is not static). The results also show that participants click more often when encountering the other's avatar compared to the other avatar's shadow. However, this increased correct clicking is not due to better recognition (the relative probability of clicking on the avatar is not higher) but rather because the avatars spend more time in front of each other. This effect emerges because the situation of 'sensing the other' while 'being sensed' is more stable than sensing an insensitive shadow. The task is solved globally even if participants are not conscious of this effect and if the solution does not appear in an individual behavioral measure.

of individual independent cognizers, we are to investigate the social interconnectivity that emerges as a result of the interaction and constrains individual-level behavior from the level of a new overarching structure.

One of the most distinctive empirical paradigms that exemplifies this idea is a perceptual crossing (PC) study (Auvray & Rohde, 2012) presented in Figure 1, in which the task is to distinguish another agent from inanimate objects. A frequent assumption in traditional explanations of social cognition is that such a recognition is accomplished by some special cognitive module (e.g. a module of agency or animacy detection) that is a precondition for interacting successfully. The results of the PC experiment (see Figure 1 caption and the original article for details) have been interpreted to show the reverse: that the social interaction itself and its particular dynamics constitute a solution to such a task. Therefore, in the oft-repeated claim by enactivists, *social interaction constitutes social cognition*.

Despite a theoretical and empirical research program on social cognition, we believe so far enactivists have not been sufficiently explicit about the explanatory methodology they subscribe to, by which we mean clarity on what is their explanatory target and what constitutes an explanation (Cummins, 2000; Wright & Bechtel, 2007).

Since *social interaction* is proposed as an explanation, it cannot be what enactivists are trying to explain. It would mean that the explanandum is perhaps *social cognition* or *experience* but these are traditionally understood as individual-level phenomena[2]. If an explanandum is to be re-construed on a supra-personal level, we need an account of social cognition on that level (without equating it with social interaction). Enactivists could, for example, take more precisely defined types of interaction as their phenomena of interest (cooperation, competition, exchange) and then seek non-individual explanations for their emergence. Our proposal discussed in the last section is to shift to a multi-level explanandum.

Moving on to the model of explanation, an explicit commitment on what constitutes an (good) explanation is important so that any given instance can be judged as to whether it succeeds. In contemporary cognitive science two explanatory frameworks have been discussed most widely: a deductive-nomological (DN) and a mechanistic one (Cummins, 2000)[3].

According to a DN framework, explaining a particular phenomenon proceeds by citing relevant general laws, the details of particular circumstances, and how the phenomenon is to be expected given these two pieces of knowledge. Such an explanation has a form of a deductive argument that derives the explanandum from a certain law taken as a premise (Hempel, 1965). Many REC-ers have explicitly argued for adopting the DN framework for explaining cognition (Walmsley, 2008).

By contrast, in a mechanistic framework, one wants to know not just *that* a certain regularity holds and *what* it is but also *why* it holds and *how* it is implemented. An answer to this question is sought in identifying a mechanism, where:

> A mechanism is a structure performing a function in virtue of its component parts, component operations, and their organization. The orchestrated functioning of the mechanism is responsible for one or more phenomena (Bechtel & Abrahamsen, 2005, p. 423).

Enactivists have not explicitly accepted or rejected either of the frameworks. However, given the similarity between them and other proponents of REC, it seems safe to assume that their implicit notion of explanation is likely closer to the DN framework. We now proceed to considering the reasons behind this preference and show that in fact there can be enactive mechanistic explanations.

[2]This interpretation is suggested by a version of the task by (Froese, Iizuka, & Ikegami, 2014) in which participants' experience of the other's presence is one of the dependent variables.

[3]The reader should be aware that this is a necessary oversimplification of the variety of positions held within philosophy of science overall and that even within cognitive science there are heated debates on the precise understanding of deductive-nomological, probabilistic, rational, mechanistic and other explanations. We merely focus on the distinction that has been most widely used in discussions between traditional cognitive science and REC.

Enactivist Worries about Mechanistic Explanation

Since space is limited we will focus on just two worries that prevent enactivists from adopting a mechanistic approach. We acknowledge that there are other issues that could be raised (e.g. the role of representations in mechanistic explanation) but our reply to them would be similar in spirit to what we offer here: that the notion of mechanism is richer and more flexible than typical complaints about it presuppose.

The Decomposability Worry

The main worry enactivists and other REC-ers seem to have with the mechanistic approach is that it allegedly views cognitive systems as decomposable or near-decomposable while in reality they are non-decomposable. For example, Lamb and Chemero (2014) argue that according to the mechanists, producing an explanation requires (1) "decomposition [that] involves developing a model of a system's behavior by identifying discrete component parts and their linear, or weakly non-linear, interactions" and (2) "localization [that] involves mapping those discrete components and interactions onto features of a physical system" (pp. 809-810). What is often added to this charge is that such an explanatory strategy views cognitive systems as *component-dominant*, i.e. the behavior of the whole is a simple additive result of the behavior of its components, whose properties and functions are rigid and pre-determined (Favela, 2015). Therefore, a single component can be analyzed in isolation as responsible for some particular capacity of the system.

In an opposition to this view on the brain and cognition, REC-ers argue that in fact living cognitive systems are non-decomposable into components and *interaction-dominant*. That is, the behavior of the whole is more than a simple sum of the parts because interactions between parts are mostly non-linear, the behavior of each part dynamically depends on all other parts of the system and it is not possible to assign any specific task to any component. Therefore, interactions between components are more important than the components themselves (Richardson & Chemero, 2014)[4].

If neural and cognitive systems are indeed non-decomposable and mechanistic framework can only be applied to decomposable systems, then obviously enactivists cannot make use of it. However, these arguments betray a misunderstanding of the mechanistic framework and explicit dismissal of the new developments in this field.

First of all, mechanists explicitly argue against mere aggregation of components and place heavy emphasis on their organization (Wimsatt, 1997). It is because the way parts are organized in space and time that they *together* can exhibit behavior that they cannot exhibit on their own. It is because the parts are on a lower level than the whole they comprise that they cannot have the same properties (cf. the properties of hydrogen and oxygen vs water).

Second, there is no reason to suppose that only linear and sequential modes of organization are allowed in mechanisms. Especially when dealing with biological mechanisms, non-linear and cyclic modes are ever-present. Such a focus on biology has led mechanists to stress the necessity for *dynamic mechanistic explanation* because in a system organized non-linearly "the operations performed by parts of the mechanism vary dynamically, depending on activity elsewhere in the mechanism" (Bechtel, 2011, p. 551). Therefore, an explanation has to include not just a static diagram of components and their organization but also a description of how the functioning of these parts is orchestrated in time, including potential shifts of the overall functional organization. Adding dynamics to a mechanistic explanation does not turn it into a law-based explanation (Bechtel & Abrahamsen, 2010, 2011).

The general thrust of these extensions of the mechanistic framework is to stress that cognitive systems are likely to lie on a continuum between the extremes of non-decomposable and fully-decomposable. They are, instead, *integrated* systems, in which it is still possible to identify components but their functions are not necessarily predetermined and fixed. Nor is there a trivial additive relationship between component sub-functions and the overall phenomenon. Rather, their contribution to the operation of the whole might dynamically depend on other parts of the system, the larger context and be variable in time. It does not mean that when studying a mechanism for a particular phenomenon it is impossible to identify these contributions (see also Menary, 2007).

In reply to such arguments, Lamb and Chemero (2014) state that

> If a neo-mechanist wishes to discard the condition of decomposability, then she does so at the cost of discarding the feature of neo-mechanistic explanations that makes them distinct from more general accounts of naturalistic explanation (p. 813).

We wish to oppose this complaint. First, it is unreasonable to expect that a certain concept or theory once proposed cannot be developed further. Second, what is distinctive about mechanistic explanations is not decomposability but a concern for causal structure underlying the phenomenon[5], and for explaining *how* things work rather than merely stating *what* are the laws. Finally, specific for the topic of this paper, a REC-er has yet to justify to what extent non-decomposability applies to social cognition, even if it holds for the brain.

[4]This view composed of several statements can of course be translated into a continuum of positions. Arguing against the explanatory primacy of components might mean rejecting explanations that (a) ignore interactions, (b) assume only linear interactions, (c) assume only static interactions ignoring dynamics, (d) ignore the effect of parameters external to the system. We thank anonymous reviewer for pointing this out.

[5]We should note here that it might be that the mechanistic approach and enactivism rely on different notions of causality that make them incompatible. Addressing this possibility would require not merely examining the respective commitments but also the plausibility of particular models of causality assumed, e.g. whether circular causality typically adopted by enactivists is a helpful notion.

The Extended Cognition Worry

The second major worry enactivists have about mechanistic explanation has to do with the claim that social interaction itself *constitutes* social cognition. This is in line with a general REC view that cognition is not done by the brain alone but by an extended brain-body-environment system. In the case of social cognition, it is rather an extended brain-body-environment-body-brain system (Froese, Iizuka, & Ikegami, 2013). The fear is that perhaps mechanistic framework somehow precludes such an extended conception of cognition.

The worry is seemingly justified by the following critique by Herschbach (2012). In his article on social cognition sub-titled "A mechanistic *alternative* to enactivism" (emphasis added), he very acutely points out that enactivists have not been very clear on what they mean by constitution in their claim that "social interaction constitutes social cognition". Constitution is standardly taken to imply a part-whole relationship and if the claim is that supra-personal interaction constitutes individual cognition, then it is somehow a category mistake and a confusion of levels of organization. On the other hand, if constitution is aimed at emphasizing the causal links between agents engaged in the interaction, then enactivists are committing a well-known coupling-constitution fallacy (Adams & Aizawa, 2010). In this fallacy, frequently ascribed to proponents of extended cognition in general, one points out extensive causal coupling between a cognitive agent and some external factors and then concludes that therefore these factors are part of cognition. Such a conclusion is thought to be unwarranted because coupling and constitutive relations are in general not equivalent.

Herschbach proposes that adopting a mechanistic framework can capture everything that enactivists want to say about social interaction without committing the fallacy. He states that perceptual crossing example would be described by a mechanist as a network composed of interacting agents to be explained by focusing on the agents, their behavior and organization. A mechanist would then move one level down to the internal mechanisms of the agents and how they produce the particular behavior observed in the experiment in response to particular sensory input. The main point of difference between enactivists and mechanists, according to Herschbach, is that while the former would like to say that the environmental input constitutes social cognition, the latter would say that only the agent-internal mechanism constitutes the phenomenon of interest (the behavior exhibited in the experiment) while the environmental input is merely an external influence on that mechanism. That is, the mechanism succeeds only when situated in the appropriate social context of having contact with another agent.

Herschbach grounds this conclusion on the fact that only parts that participate in a self-organized autonomous individual can be truly said to constitute cognition. He follows Bechtel (2009) who has argued that it is the autonomous living system that is the proper "locus of control", differentiated from the environment, because it is the living system that needs to maintain itself as a unity in constantly changing external conditions.

If adopting a mechanistic framework were to indeed preclude speaking of social interaction playing a constitutive role, enactivists would not be able to accept it. However, we believe there are reasons to oppose Herschbach's conclusion.

The first most obvious reply to Herschbach is that he is replacing the enactive explanandum with his own by switching from the phenomenon of interest being social interaction as a whole to the behavior of the individual. Even though enactivists have not been very clear on their exact explanandum, they would definitely resist this move from the higher to the lower level.

Furthermore, regarding autonomy as a guide to the boundaries of cognition, both Herschbach and Bechtel misunderstand the notion of autonomy adopted by enactivists. Living systems are autonomous in being self-determined rather than being steered from outside (Bechtel's "locus of control"). However, they are also autonomous in being operationally closed, that is, organized in a circular manner, in which the processes and components that constitute the system are themselves constituted by that system. This, however, applies not just to the bio-chemical processes of self-maintenance, but also to the closure of the sensorimotor loop of the organism. This loop is closed not *to* the environment but *through* the environment, which is merely an additional step in the loop, not an input or output external to the system (see Villalobos & Ward, 2015, for a more detailed argument). The point here is that enactivist autonomy does allow for the constitutive role of the environment in the cognitive process.

Finally, to respond to Herschbach from within a mechanistic framework itself is to point at the recent literature that treats the coupling-constitution fallacy as an instance of a general problem of demarcating the boundaries of a mechanism (Kaplan, 2012). In short, what is required to allow for deciding what constitutes part of the mechanism is an account of *constitutive explanatory relevance*, i.e. a way to determine which components and processes are *relevant* to a particular mechanistic explanation (Craver, 2007). This does not need to be a priori based on deciding what cognition really is and whether it really extends beyond the brain. In fact, it is even possible to develop a deflationary (yet still mechanistic) account which shows how certain kinds of dynamic non-linear coupling just are constitutive (Kirchhoff, 2016).

In sum, contra Herschbach (2012), adopting the mechanistic framework does not in fact necessitate abandoning the constitutive role of social interaction in social cognition.

The Enactive Mechanisms Proposal

We believe enactive mechanistic explanation is possible as there is sufficient basis on both sides of the debate for such a reconciliation. Constructing such an account requires two things. First, it requires disambiguation of the notion of 'composition' involved in mechanistic explanations to recognize its compatibility with enactivist claims about non-

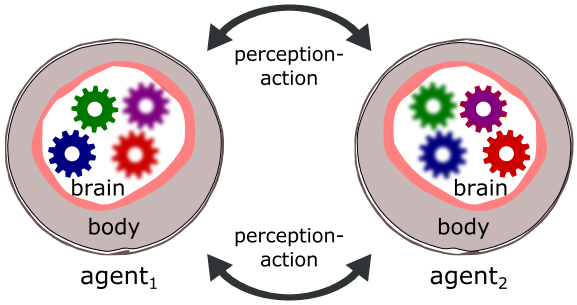

Figure 2: Traditional social cognition.

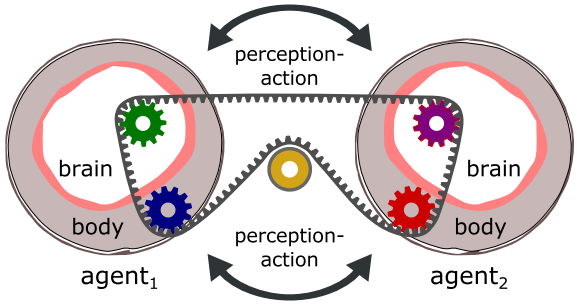

Figure 3: Enactive social cognition.

decomposability of cognitive systems. Identifying components in a cognitive system does not necessarily entail that these components are self-contained, so that the mechanism is a mere linear addition and causal interrelation of them. We can just as well identify components that are defined by their role in the overall whole. This latter, holistic, notion of 'component' is in line with enactivism. Crucially, though, it does leave room for a mechanistic explanation. Secondly, a tailoring of the mechanistic framework is required to fit wider enactivist commitments, such as, for example, making room for cognitive mechanisms that are non-representational and extended. This reorientation towards mechanisms can be advantageous to enactivists for several reasons.

First, it equips enactivism with an explicit and coherent explanatory framework, which comes with specific tools and strategies for constructing explanations of cognitive phenomena. For example, mechanistic literature on mutual manipulability as a guide to constitutive relevance (Craver, 2007) can help make clear what elements of individual cognition and social interaction are essential to particular tasks. Similarly, discussions on how to think of inter-level causation (Craver & Bechtel, 2007) can help understand the autonomy of the supra-personal level that enactivists consider important.

Second, the claim that social interaction itself should constitute the primary level of explanation in enactive work on sociality to some extent encourages ignoring the individual mechanisms. By contrast, mechanistic emphasis on working parts and their operations highlights the need to provide a distinctively enactive account of what goes on in the individual brains and bodies, i.e. offer a truly multi-level explanation for a multi-level explanandum. Otherwise, a traditional cognitive scientist might well acknowledge the role of interaction but combine that with a non-enactive account of internal mechanisms, thereby defying the whole purpose of constructing an explanatorily complete enactive cognitive science.

Third, enactive mechanistic explanation promotes integration with the rest of cognitive science while at the same time making clear how enactive explanations are different from traditional ones. That is, competing explanations could now be formulated in the same language and compared, instead of two communities adopting completely different explanatory frameworks and talking past each other. This is not to say that dynamical, more law-oriented approaches are to be eliminated and we definitely see value in a pluralistic attitude (Dale, Dietrich, & Chemero, 2009). However, we think at least some intersection is essential for continued progress.

The 'commensurability' of mechanistic enactivism and traditional cognitive science can be illustrated schematically. Figure 2 represents a traditional cognitive science approach to social cognition. All the components of the cognitive mechanisms (differently colored cogs) are located inside the agents' brains. Succeeding in a social task requires one agent to "replicate" the cogs of the other agent inside their own brain, i.e. internally represent the mental states of the other by means of "theory of mind" or simulation. The replicated cogs will not be the same as the original ones (hence the blurriness) but need to be sufficiently close if the agents are to interact successfully. The unfolding of the interaction is then explained in terms of the operations of this internal machinery, giving a strong impression that once all the cogs are in place, the whole process might as well proceed offline.

The contrasting enactive mechanistic view is depicted in Figure 3. Here the explanandum is particular kinds of social interactions in which the individuals participate. The explanation is to be achieved by specifying all the components of the picture that contribute to the realization of such interactions. The components of the cognitive mechanisms (the cogs) are distributed across the brain and the body of both agents and dynamically coupled (the toothed belt), respecting the enactivist rejection of the internal-external dichotomy. The contribution of the individual brains to the overall social interaction is diminished with respect to the previous figure, suggesting a need for an alternative account of such internal mechanisms. The fact that the coupling is a constraint on individual mechanisms rather than an additional cog, expresses the idea that *interaction consists of interacting individuals* yet allowing for emergent effects. Furthermore, the picture includes the possibility that the coupling might be affected by contextual factors (the tension pulley), such as the layout of the environment in which interaction unfolds, or some sociocultural circumstances.

To restate the point of our paper in terms of the second figure above, we believe the current state of the matters in enactivist theorizing about social cognition is an exclusive focus on the toothed belt. We think the time is ripe to start examining the rest of the picture.

Acknowledgments

The first author is funded by the Netherlands Organization for Scientific Research (NWO), research project PGW-12-32.

References

Adams, F., & Aizawa, K. (2010). Defending the bounds of cognition. *The Extended Mind*, 67–80.

Auvray, M., & Rohde, M. (2012). Perceptual crossing: The simplest online paradigm. *Frontiers in Human Neuroscience*, *6*, 181.

Bechtel, W. (2009). Explanation: Mechanism, modularity, and situated cognition. In P. Robbins & M. Aydede (Eds.), *The cambridge handbook of situated cognition* (pp. 155–170). Cambridge: Cambridge University Press.

Bechtel, W. (2011). Mechanism and biological explanation. *Philosophy of science*, *78*(4), 533–557.

Bechtel, W., & Abrahamsen, A. (2005). Explanation: A mechanist alternative. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *36*(2), 421–441.

Bechtel, W., & Abrahamsen, A. (2010). Dynamic mechanistic explanation: Computational modeling of circadian rhythms as an exemplar for cognitive science. *Studies in History and Philosophy of Science Part A*, *41*(3), 321–333.

Bechtel, W., & Abrahamsen, A. (2011). Complex biological mechanisms: Cyclic, oscillatory, and autonomous. In C. A. Hooker (Ed.), *Philosophy of complex systems* (pp. 257–285). New York: Elsevier.

Craver, C. F. (2007). Constitutive explanatory relevance. *Journal of Philosophical Research*, *32*, 3–20.

Craver, C. F., & Bechtel, W. (2007, 1 September). Top-down causation without top-down causes. *Biology & philosophy*, *22*(4), 547–563.

Cummins, R. (2000). "How does it work?" versus "what are the laws?": Two conceptions of psychological explanation. In F. Keil & R. Wilson (Eds.), *Explanation and cognition* (pp. 117–145). Cambridge, MA: MIT Press.

Dale, R., Dietrich, E., & Chemero, A. (2009). Explanatory pluralism in cognitive science. *Cognitive Science*, *33*(5), 739–742.

Eerland, A., Guadalupe, T. M., & Zwaan, R. A. (2011). Leaning to the left makes the eiffel tower seem smaller: Posture-modulated estimation. *Psychological Science*, *22*(12), 1511–1514.

Favela, L. H., Jr. (2015). *Understanding cognition via complexity science*. Unpublished doctoral dissertation, University of Cincinnati.

Froese, T., Iizuka, H., & Ikegami, T. (2013). From synthetic modeling of social interaction to dynamic theories of brain–body–environment–body–brain systems. *The Behavioral and Brain Sciences*, *36*(04), 420–421.

Froese, T., Iizuka, H., & Ikegami, T. (2014). Embodied social interaction constitutes social cognition in pairs of humans: A minimalist virtual reality experiment. *Scientific Reports*, *4*(3672).

Hempel, C. (1965). *Aspects of scientific explanation and other essays in the philosophy of science*. New York: Free Press.

Herschbach, M. (2012). On the role of social interaction in social cognition: A mechanistic alternative to enactivism. *Phenomenology and the Cognitive Sciences*, *11*(4), 467–486.

Kaplan, D. M. (2012). How to demarcate the boundaries of cognition. *Biology & Philosophy*, *27*(4), 545–570.

Kirchhoff, M. D. (2016). From mutual manipulation to cognitive extension: Challenges and implications. *Phenomenology and the Cognitive Sciences*, 1–16.

Lamb, M., & Chemero, A. (2014). Structure and application of dynamical models in cognitive science. In *Proceedings of the 36th annual meeting of the cognitive science society* (pp. 809–814).

Marsh, K. L., Johnston, L., Richardson, M. J., & Schmidt, R. C. (2009). Toward a radically embodied, embedded social psychology. *European Journal of Social Psychology*, *39*(7), 1217–1225.

Maturana, H., & Varela, F. (1980). *Autopoiesis and cognition: The realization of the living*. Boston: D Reidel Publishing.

McGee, K. (2005). Enactive cognitive science, part 1: Background and research themes. *Constructivist Foundations*, *1*(1), 19–34.

Menary, R. (2007). *Cognitive integration: Mind and cognition unbounded*. Palgrave Macmillan.

Richardson, M. J., & Chemero, A. (2014). Complex dynamical systems and embodiment. In L. Shapiro (Ed.), *The routledge handbook of embodied cognition* (pp. 39–50). New York: Routledge.

van Dijk, J., Kerkhofs, R., van Rooij, I., & Haselager, P. (2008). Can there be such a thing as embodied embedded cognitive neuroscience? *Theory & Psychology*, *18*(3), 297–316.

Varela, F., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge: MIT Press.

Villalobos, M., & Ward, D. (2015). Living systems: Autonomy, autopoiesis and enaction. *Philosophy & Technology*, *28*(2), 225–239.

Walmsley, J. (2008). Explanation in dynamical cognitive science. *Minds and Machines*, *18*(3), 331–348.

Wilson, A. D., & Golonka, S. (2013). Embodied cognition is not what you think it is. *Frontiers in Psychology*, *4*, 58.

Wimsatt, W. C. (1997). Aggregativity: Reductive heuristics for finding emergence. *Philosophy of Science*, *64*, 372–384.

Wright, C. D., & Bechtel, W. (2007). Mechanisms and psychological explanation. *Philosophy of Psychology and Cognitive Science*, *4*, 31–79.