There *Is* a Special Problem of Scientific Representation

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Callender and Cohen argue that there is no need for a special account of the constitution of scientific representation. I argue that scientific representation is communal and therefore deeply tied to the practice in which it is embedded. The communal nature is accounted for by *licensing*, the activities of scientific practice by which scientists establish a representation. A case study of the Lotka-Volterra model reveals how licensure is a constitutive element of the representational relationship. Thus, any account of the constitution of scientific representation must account for licensing, meaning that there *is* a special problem of scientific representation.

1. Introduction. According to many philosophers of science, representation in scientific practice is different from representation in other disciplines such as art and language. This claim is denied by Callender and Cohen (2006), who argue that representation is the same across disciplines. In this article, I will argue that their view leaves the communal nature of scientific representation unexplained. To explain how scientific representation is dependent upon practice, I will introduce the concept of *licensing*, in which the targets of representational vehicles are determined through various activities performed by scientists in accord with broader scientific practice. I will argue that licensure is a constitutive feature of representation in science, indicating that there *is* a special problem of scientific representation.

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2. Callendar and Cohen's View. On Callender and Cohen's (2006, 67) evaluation, much of the literature on scientific representation has been "concerned with non-issues."[1] Specifically, they think there is no reason for philosophers of science to give a special account of the "constitution question": "What constitutes the representational relation between a model and the world?" (68). In response to this question, they make a few observations. One is that it is "economical and natural to explain some types of representation in terms of other, more basic types of representation" (70). They also identify a general desire to have a consistent account of how "entities other than models—language, pictures, mental states, and so on— . . . represent the very same targets that models represent" (71). For these reasons, they suggest that "scientific representation is just one more special case of derivative representation" (75). That is to say, the representational nature of scientific vehicles is explained in the same way that the representational nature of linguistic entities, artwork, and so on, is explained. In each case, and in every practice, the representational nature in question will be reduced to a more fundamental representational entity. So, for instance, the representational nature of a word, a painting, and a scientific model will each be explained in terms of the representational nature of mental states.

On Callender and Cohen's (2006, 74) view, representation is purely stipulative: "Virtually anything can be stipulated to be a representational vehicle for the representation of virtually anything." Of course, it is not the case that any stipulated representation will actually be useful for scientific aims. Thus, they identify pragmatic constraints that delimit scientific representation. However, they make it quite clear that these constraints are delimiting already existing representations. As such, the pragmatic constraints are not a part of an account of the constitution of representation itself: "The questions about the utility of these representational vehicles are questions about the pragmatics of things that are representational vehicles, not questions about their representational status per se" (75).

If Callender and Cohen are correct, then we are left rethinking a rather extensive literature on scientific representation that typically begins with the assumption that there is something special about representation in science.[2] As one example among many, Suárez (2004) defends an inferential concep-

1. Zuppone (2014) argues in favor of Callender and Cohen's evaluation, suggesting that there are normative but not substantive or constitutive differences in representation between art and science.

2. For more accounts that answer the constitution question in a distinctive way, see the work of, e.g., Giere (1988, 2004); van Fraassen (1980, 2008); Hughes (1997); French, Ladyman, and Bueno (French and Ladyman 1999; Bueno and French 2011); and Contessa (2007). For an overview of these accounts of scientific representation among others, see Boesch (2015), Suárez (2015), and Frigg and Nguyen (2016).

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tion of scientific representation. His account takes careful notice of the aims of scientific practice, noting that mere stipulation (what he calls "representational force") is insufficient for representation in science. To be a scientific representation, a vehicle must also permit surrogate reasoning, which "allows competent and informed agents to draw specific inferences regarding [a target]" (773). If we accept Callender and Cohen's view, then Suárez's account and the many like it do nothing more than identify some of the typical pragmatic strategies employed in delimiting representations for scientific uses (Callender and Cohen 2006, 78).

3. Private Reminiscence and Communal Representation. In order to show that the extensive literature on scientific representation has not been addressing a "non-issue," I will need to show that there is a special problem of scientific representation, a feature unexplained by Callender and Cohen's account. I submit that the relevant feature in need of special explanation is the communal nature of scientific representation, that it inherently involves reference to the practice. To see why Callender and Cohen's view is unable to account for the communal nature of scientific representation, consider what I call 'reminiscence', a representational relationship that lacks the same communal feature. It is defined schematically as follows:

> Some X is reminiscent of some Y for some agent A provided that when A thinks about or experiences X, she thinks about or experiences Y and attributes some connection between X and Y.

So, for example, a drawing can be reminiscent of my nephew, the smell of jasmine can be reminiscent of golfing, and so on.[3]

There are three noteworthy features of reminiscence. First, the representational nature of reminiscence can be reduced to the representational nature of more fundamental entities. For example, I can explain the drawing's being reminiscent of my nephew in virtue of the mental state produced by the drawing (which is about my nephew, who created it). Second, stipulation is sufficient to create an instance of reminiscence. For example, I could draw on my hand a symbol that I create for the sake of reminding me to call my nephew. The reminiscent relationship between the symbol and my nephew exists because of my stipulative act. Finally, any limitations of reminiscent relationships will be made for pragmatic reasons. For example, it would be for pragmatic reasons that I make the symbol on my hand look like the ball from his favorite sport, since it will more easily remind me of him.

3. I should note that the account of reminiscence here is not meant as a detailed explanation of this concept but only as an analogy to draw a point about representation.

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These three features of reminiscence are noteworthy because they are shared by Callender and Cohen's view of scientific representation. In fact, from Callender and Cohen's perspective, the only major difference between the two concepts would be the particular aims for which each relationship is utilized. While important, these different aims alone are insufficient to explain a key dissimilarity between scientific representation and reminiscence: while reminiscence can be private, scientific representation is necessarily communal. That reminiscence can be private can be seen from the fact that discussions of reminiscence can terminate in disagreement. For example, no one is ultimately 'correct' about whether or not a drawing is reminiscent of my nephew. This is because reminiscence is agent-relative and so depends only upon some particular agent and her mental states.

Scientific representation relies on much more. As Suárez (2010, 99) has argued, "Representation is not at all 'in the mind' of any particular agent. It is rather 'in the world,' and more particularly in the social world—as a prominent activity or set of activities carried out by those communities of inquirers involved in the practice of scientific modeling." Scientific representation is not isolated from the practice in which it is embedded. It is necessarily communal.[4] The communal nature is demonstrated from the fact that representational vehicles demonstrate autonomy from individual scientists and their mental states.[5] For example, a scientist's rogue stipulation that the Lotka-Volterra model (which represents predator-prey relations) represents population change owing to genetic drift does not count as an instance of scientific representation. This is not only because it does not (pragmatically) allow for meaningful insights but also because it ignores and discounts the autonomous elements of the model as understood and developed by the broader scientific community.[6] The autonomous elements are seen in the materiality or historicity of the representational vehicle—in its development, reception, and contemporary use. Understanding how and why the scientific object represents its target requires paying attention to these communal features.[7] That is

4. The view of representation argued for in this article echoes many of the points made by Wittgenstein in his "Private Language Argument," in which he argues that meaning is necessarily communal (1953/2009, 95^{e}–111^{e}).

5. A similar point about the autonomy of models (from both theory and the world) has been made by Morgan and Morrison (1999). Here, I am extending a related point to other representational vehicles, including things like diagrams and figures, arguing that they are autonomous from the mental states of individual scientists.

6. Of course, there may be disagreements and developments internal to the practice about how to use some representation, but these disagreements and developments are part of the practice.

7. According to Latour (2014, 347), the peculiarities of scientific image-making (which include the communal features I describe below) "[offer] an excellent way to define what is 'scientific,' after all, in science."

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to say that the communal features are partially constitutive of the representational relationship. Callender and Cohen's account of scientific representation does not sufficiently account for these constitutive communal elements, as will be shown more explicitly below.

4. Licensing. Explaining the communal nature of scientific representation requires that attention be given to the material, autonomous dimensions of the representational vehicle in terms of its development, reception, and use. All of these features partially establish a scientific representation, through an activity I call licensing. Licensing is the set of activities of scientific practice by which scientists establish the representational relationship between a vehicle and its target. It is through licensing that scientists and the broader scientific community establish what Suárez (2004, 768) calls the "intended representational uses" of a vehicle. Licensing is itself a constitutive element of the representational relationship: it plays a critical role in explaining how and why some vehicle represents its target. Seeing the sorts of activities involved in licensing and how they partially constitute the representational relationship will require that we pay close attention to the historical development, reception, and use of actual instances of scientific representations.

4.1. Licensing in Artistic Representation. A similar sort of licensing is present in representation in art, and so an initial pass on the concept as it applies to artistic practice will be of use in drawing an analogy to licensing in science.[8] To see the role of licensing in artistic representation, consider an example. The mere stipulation that Pablo Picasso's *Guernica* should represent the pain of cyberbullying is clearly insufficient to make it represent this target. Understanding how *Guernica* is representational involves an awareness of communal features: Picasso's intentions within the environment in which he created the painting, how the painting was received by viewers in the years following its creation, and how it is understood today. With these features in mind, it is clear that *Guernica* represents the pain and suffering of the people of Guernica, who were bombed by Axis forces at the request of Francisco Franco and the Spanish Nationalists. The licensing here is a constitutive element of *Guernica*'s representational nature: without these features, it is not clear whether or how the painting would manage to represent anything at all.

Licensing also occurs outside of the scope of authorial intent, when the artistic community comes to accept that a piece of art is representational in

8. It is somewhat contentious to draw conclusions about the nature of representation in science by appeal to art; see, e.g., Bueno and French (2011). Nonetheless, it is a common technique in discussions of scientific representation; see, e.g., Suárez (2004).

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a way that was not intended by the author. A good example can be taken from an anecdote related by the author Flannery O'Connor (1988, 853): "A student asked me . . . : 'Miss O'Connor, what is the significance of the Misfit's hat?' Of course, I had no idea the Misfit's hat was significant, but finally I managed to say, 'Its significance is to cover his head.'" The Misfit is a key character in O'Connor's famous short story "A Good Man Is Hard to Find," and, as such, it would not be surprising for his wardrobe to be importantly representational. Her answer indicates that while she did not intend any representational target for the hat, there may yet be one. If the hat is representational, it will not be owing to her authorial intent but rather to the views of the broader artistic community.

Let me make it very clear that the licensure so far described is not already accounted for by elements of Callender and Cohen's account. First, note that none of these means of licensing is a mere pragmatic limitation of already existing representations. It is not as if *Guernica* represents anything and everything but is then limited by the contexts of Picasso, audiences, and art historians. These contexts are a crucial part of understanding why it represents at all. Nor is the licensing mere stipulation. O'Connor leaves it open that there may be a representational target for the Misfit's hat, even though she did not stipulate one. A single reader's stipulation alone is insufficient to make it a representation, since the target must also fit well with the Misfit's characteristics, with O'Connor's general themes as understood by literary critics and audiences alike, and so on. Once again, these contexts are a critical part of establishing the representational nature of the hat.

4.2. Licensing in Scientific Representation: A Case Study. The unique aims of science indicate that the licensing of scientific representation is of a different kind than the licensing in art. All the same, licensing similarly plays a critical role in establishing scientific representation. According to Knuuttila (2014, 304), case studies of scientific representation have revealed that it is "a complicated phenomenon" and "a laborious art." Understanding the nature of licensing and its role in the complexities of scientific representation will be best accomplished by examining the complicated features seen in the context of a case study. Examples could be made of any type of representational vehicle, like the masterful case study of a scientific figure made by Latour (1999). I will take as my example the Lotka-Volterra model, since its development exhibits interesting features, many of which have already been widely discussed by other philosophers (e.g., Knuuttila and Loettgers 2011, 2016).

As mentioned above, the Lotka-Volterra model is used by ecologists to represent predator-prey relations. It had its beginnings in the independent work of two different scientists, Vito Volterra and Alfred Lotka. In understanding the representational nature of this model, it is important to pay at-

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tention to its licensing through its historical development. This attention includes noticing things like the way that the construction of the model by Lotka, Volterra, and others has been responsive to certain theoretical and empirical aims. These historical and practice-centered features of the model's development reveal the partial autonomy of its representational nature. These features make up the licensing, which is itself partially constitutive of the representational nature of the model, since understanding how and why the model represents its targets requires attending to these features. Let us now turn to examine these features in more detail.

Consider first the development of the model by Volterra, who was "motivated by the goal of reproducing the kind of oscillating behavior that was observed empirically in fishery statistics" (Knuuttila and Loettgers 2016, 19). His aim of addressing a theoretical question with an empirically useful model is central not only to understanding how the model historically came about but to understanding how it represents its targets. Consider how Volterra (1928, 5) described his project and the aims that permeate his description: "Let us seek to express in words the way the phenomenon proceeds roughly: afterwards let us translate these words into mathematical language. This leads to the formulation of differential equations. If then we allow ourselves to be guided by the methods of analysis we are led much farther than the language and ordinary reasoning would be able to carry us and can formulate precise mathematical laws. These do not contradict the results of observation. Rather the most important of these seems in perfect accord with the statistical results."

Volterra's actual process of moving from words, to equation, to application of results (for both theoretical and empirical purposes) first involved creating an equation to account for the population change of a single species. He then added additional species and modeled interactions under different conditions, including, notably, contending for the same food and the predation of one species upon the other. Using these models, he demonstrated "three fundamental laws of the fluctuations of the two species living together" (1928, 20). He then applied these theoretical laws of predator-prey relations to the empirical case that had prompted his analysis, the peculiar rise in predator populations during the decrease in the fishing of prey populations in the Adriatic Sea during World War I (21).

Why does Volterra's model represent these theoretical features of predator-prey relations? Why does it represent the populations of fish in the Adriatic during World War I? It represents these targets because, through a series of steps of analysis, revision, and development, each of which was responsive to certain theoretical and empirical aims understood and described in his account, Volterra established this representational nature. Indeed, as explained by Knuuttila and Loettgers (2016), the historical development of this model has a much more extended history than the one Volterra described in the two

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papers in which he first introduced it (1926, 1928). The model is a representation of its target not by mere stipulation and pragmatic constraint but through careful and attentive construction of equations that ensure that the model functions in the wider theoretical contexts and can account for the relevant empirical details. In short, the model represents its targets because Volterra so licensed it by building into the model these external, autonomous representational features. Without these features, how or what would it represent?

Consider another instance of licensing in the development of the Lotka-Volterra model, this time by Lotka. His development proceeded with a different aim than Volterra had: "Instead of starting from the different simple cases and generalizing from them, he developed a highly abstract and general model template that could be applied in modelling various kinds of systems" (Knuuttila and Loettgers 2016, 13). He began by creating a very general equation that described "evolution as a process of redistribution of matter among the several components . . . of the system" (15). In two papers, Lotka (1920a, 1920b) applied this general equation to particular cases in biology and chemistry, in each case coming to theoretical conclusions about the systems in question. For example, in applying the equation to a predator-prey system, he concluded that there would be "undamped oscillation continuing indefinitely" among the two populations (1920a, 414). Lotka did not specifically apply the results to any empirical data but instead used his results to come to theoretical conclusions about these relationships that he then connected to theoretical ecological principles drawn from Herbert Spencer's *First Principles* (414).

Why does Lotka's model represent its theoretical target? What constitutes this representational relationship? Any attempt to explain the representational relationship must reference the way in which Lotka derived his general equation and the way in which he applied it to the specific cases. That is to say, the representational nature of the model is constructed through the scientific activities performed by Lotka during the development of the model. Lotka does not merely stipulate that his model targets predator-prey relationships. Instead, he builds this ability into the model during the development of the general equation and further constructs this ability in his application of the question to specific targets. In so doing, he partially constructs the representational nature of the model—he licenses it as a representation through activities in accord with the broader practice.

The history of the Lotka-Volterra model since its initial development is long and complex. As such, the licensing of the model goes beyond the initial work of Lotka and Volterra—similar to how the licensing of O'Connor's story goes beyond her initial work. As described by Berryman (1992), one development was a shift in the 1940s to the use of a logistic formulation that allowed for attention to be placed on predator-prey ratios rather than products. Another development, which occurred around the same time, was the use of

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a predator functional response that introduced a nonlinear rate of death for the prey. Each of these developments license new representational targets by expanding and altering the model to make it responsive to different theoretical or empirical aims, by removing idealizations, or otherwise by allowing for different theoretical conclusions. Many other variations of the Lotka-Volterra model exist, licensed by similar developments. As just one example, Goodwin (1967) modified the model to apply to questions in economics. Additionally, the original formulation of the model is still used in introductory textbooks on ecology (see, e.g., Cain, Bowman, and Hacker 2008). The representational nature of the model in each of these cases is partially established by these features of the model that stand independent of any mental states of scientists and students alike. Scientists do not merely start using a model however they would like, without recourse to the history of the use of the model. There are autonomous elements of the model that are carried with it when it changes contexts in virtue of how it was originally developed and how the broader scientific practice has come to use and understand it over time (Knuuttila and Loettgers 2014). In short, the constitution of the representational nature of the Lotka-Volterra model relies deeply upon these historical features of licensing as understood by the broader scientific community.

Let me briefly underscore the importance of these activities of licensing to the representational nature of the Lotka-Volterra model by imagining a scenario in which these features are absent. Suppose that Volterra and Lotka had proceeded differently. Suppose that they began, for no particular reason, by drawing a five-pointed star and stipulated that it represented predator-prey relations. What is the status of this star, qua representation? It is not as if the star really is a scientific representation, albeit a bad one, of predator-prey relations. Rather, the star plainly fails to be a scientific representation at all. Indeed, Giraud's (2014) study of the Laffer curve in economics reveals that bad scientific representations still include significant elements of what I have called licensing. Scientific representations, good and bad, are all constructed to assist in answering certain questions, explaining certain phenomena, and understanding certain target systems. It is through licensing that scientists and the broader scientific community build into and around the vehicle the features and interpretations capable of achieving these aims. A vehicle without licensing lacks these features and interpretations. As such, it is not just a bad representation; indeed, it is not a representation at all. A discussion of the representational nature of vehicles that lack these features is either infelicitous or involves an equivocation of the word 'representation'. A view of scientific representation that equally counts both the star and the Lotka-Volterra model as full scientific representations, even if it specifies one as good and one as bad, underestimates the role of these historical features of the model. They are not external to the representational nature of the vehicle but are

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themselves an essential constitutive element of its representational nature: without these features, the vehicle is not a scientific representation at all.

5. The Special Problem of Scientific Representation. If I am right that licensing is a necessary constitutive feature of scientific representation that explains its communal nature, then contrary to Callender and Cohen's suggestion, we cannot pull the question of the constitution of representation away from questions of practice. A scientific object represents its target not (only) because there is some stipulation and pragmatic constraint but also in virtue of licensing: the context in which it was created, the application of theoretical and empirical constraints, the awareness of and management of idealizations, and the history of its reception and use. Accounting for whether and how a scientific object represents its target will always require reference to these features that partially establish the representational nature. Thus, there *is* a special problem of scientific representation.

I should note that I am not here arguing for a stronger counterclaim to Callender and Cohen's that says that accounts of the representational nature of mental states are without any value to the constitution question of scientific representation. But my argument does indicate that an account of the representational nature of mental states alone is insufficient to account for scientific representation. Put otherwise: even if tomorrow we had a solid, universally accepted account of the representational nature of mental states, we would not yet have a complete account of scientific representation. We would still need an account of the deep reliance that it has upon the practice in which it is embedded. Thus, while our discussion of the constitution of scientific representation might include reference to the representational nature of mental states, it must also include reference to what I have described here as the licensing by the practice.

A different concern is that the use of the word 'special' is a bit deceptive. What I have identified here as the 'special' problem of scientific representation turns out to be a common feature of representation across disciplines, since, for example, I have suggested that it holds of artistic representation as well. While it is true that, according to my argument, an account of artistic representation will likely take account of licensing as well, it does not indicate that it is the same type of licensing in both practices. Indeed, given the unique aims that mark off scientific practice, its licensing can reasonably be expected to be correspondingly unique. That is to say that understanding, knowing, or explaining the empirical world are special aims and therefore subject to special sorts of licensing. Scientific representation remains special because these features merit special attention.

We might also wonder whether it is right to continue to discuss scientific representation as a whole. If understanding representation in science requires in part that we understand the way in which scientists of a practice

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develop, utilize, and adapt these representational devices, then it is at least possible that these activities will be different within different domains. For example, the licensure of representations in physics might be rather different from that in economics. My suspicion is that, given the common, broad-scale aims of the various domains, we can still say some general things about representation in science as a whole. Nonetheless, we would do well to pay attention to representation as it occurs in these more localized contexts. Moving forward from this conclusion to develop further insights about the nature of scientific representation will involve analyzing specific representational objects or strategies as they occur in scientific practice, perhaps taking hints and clues from in-the-field investigations like those conducted by sociologists of science, for example, those in Lynch and Woolgar (1990), Latour (1999), and Coopmans et al. (2014).

6. Conclusion. Although Callender and Cohen's view remains a formidable approach to the constitution question of scientific representation, I have endeavored in this article to show why their account is insufficient and thus why this question merits continued attention by philosophers of science. Representation in science is deeply tied up with the practice in which it is embedded. The communal nature of scientific representation can be seen in the way that science, as a practice, partially constructs its representations through the activities of licensing. The licensing is not the pragmatic limitation of some already existing representations but is itself a constitutive element of the representational relationship. Any account of what it is for a scientific object to represent its target will necessarily involve reference to licensing. Thus, there *is* a special problem of scientific representation.

REFERENCES

Berryman, Alan. 1992. "The Origins and Evolution of Predator-Prey Theory." *Ecology* 73:1530–35.
Boesch, Brandon. 2015. "Scientific Representation." *Internet Encyclopedia of Philosophy*. http://www.iep.utm.edu/sci-repr/.
Bueno, Otávio, and Steven French. 2011. "How Theories Represent." *British Journal for the Philosophy of Science* 62:857–94.
Cain, Michael, William Bowman, and Sally Hacker. 2008. *Ecology*. Sunderland, MA: Sinauer.
Callender, Craig, and Jonathan Cohen. 2006. "There Is No Special Problem about Scientific Representation." *Theoria* 21:67–85.
Contessa, Gabriele. 2007. "Scientific Representation, Interpretation, and Surrogative Reasoning." *Philosophy of Science* 74:48–68.
Coopmans, Catelijne, Janet Vertesi, Michael E. Lynch, and Steve Woolgar, eds. 2014. *Representation in Scientific Practice Revisited*. Cambridge, MA: MIT Press.
French, Steven, and James Ladyman. 1999. "Reinflating the Semantic Approach." *International Studies in the Philosophy of Science* 13:103–19.
Frigg, Roman, and James Nguyen. 2016. "Scientific Representation." In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta. Stanford, CA: Stanford University. http://plato.stanford.edu/entries/scientific-representation/.
Giere, Ronald. 1988. *Explaining Science: A Cognitive Approach*. Chicago: University of Chicago Press.

https://doi.org/10.1086/693989 Published online by Cambridge University Press

———. 2004. "How Models Are Used to Represent Reality." *Philosophy of Science* 71:742–52.
Giraud, Yann. 2014. "Legitimizing Napkin Drawings: The Curious Dispersion of Laffer Curves, 1978–2008." In Coopmans et al. 2014.
Goodwin, Richard. 1967. "A Growth Cycle." In *Capitalism and Economic Growth*, ed. C. H. Feinstein, 165–70. Cambridge: Cambridge University Press.
Hughes, R. I. G. 1997. "Models and Representation." *Philosophy of Science* 64 (Proceedings): S325–S336.
Knuuttila, Tarja. 2014. "Reflexivity, Representation, and the Possibility of Constructivist Realism." In *New Directions in the Philosophy of Science*, ed. M. C. Galavotti, S. Hartmann, M. Weber, W. Gonzalez, D. Dieks, and T. Uebel, 297–312. Dordrecht: Springer.
Knuuttila, Tarja, and Andrea Loettgers. 2011. "The Productive Tension: Mechanisms vs. Templates in Modeling the Phenomenon." In *Models, Simulations, and Representations*, ed. P. Humphreys and C. Imbert, 3–24. New York: Routledge.
———. 2014. "Magnets, Spins, and Neurons: The Dissemination of Model Templates across Disciplines." *Monist* 97:280–300.
———. 2016. "Modelling as Indirect Representation? The Lotka-Volterra Model Revisited." *British Journal for the Philosophy of Science.* doi:10.1093/bjps/axv055.
Latour, Bruno. 1999. "Circulating Reference." In *Pandora's Hope*. Cambridge, MA: Harvard University Press.
———. 2014. "The More Manipulations, the Better." In Coopmans et al. 2014.
Lotka, Alfred. 1920a. "Analytical Note on Certain Rhythmic Relations in Organic Systems." *Proceedings of the National Academy of Arts and Sciences* 42:410–15.
———. 1920b. "Undamped Oscillations Derived from the Law of Mass Action." *Journal of the American Chemical Society* 42:1595–98.
Lynch, Michael E., and Steve Woolgar, eds. 1990. *Representation in Scientific Practice*. Cambridge, MA: MIT Press.
Morgan, Mary, and Margaret Morrison, eds. 1999. *Models as Mediators: Perspectives on Natural and Social Science*. New York: Cambridge University Press.
O'Connor, Flannery. 1988. "The Catholic Novelist in the Protestant South." In *Flannery O'Connor: Collected Works*, 853–64. New York: Literary Classics of the United States.
Suárez, Mauricio. 2004. "An Inferential Conception of Scientific Representation." *Philosophy of Science* 71:767–79.
———. 2010. "Scientific Representation." *Philosophy Compass* 5:91–101.
———. 2015. "Representation in Science." In *The Oxford Handbook of Philosophy of Science*, ed. P. Humphreys. New York: Oxford University Press.
van Fraassen, Bas C. 1980. *The Scientific Image*. New York: Oxford University Press.
———. 2008. *Scientific Representation: Paradoxes of Perspective*. New York: Oxford University Press.
Volterra, Vito. 1926. "Fluctuations in the Abundance of a Species Considered Mathematically." *Nature* 128:558–60.
———. 1928. "Variations and Fluctuations of the Number of Individuals in Animal Species Living Together." *Journal du Counseil international pour l'exploration de la mer* 3:3–51.
Wittgenstein, Ludwig. 1953/2009. *Philosophical Investigations*. Trans. G. E. M. Anscombe, P. M. S. Hacker, and J. Schulte. Malden, MA: Wiley-Blackwell.
Zuppone, Romina. 2014. "¿Existen diferencias esenciales entre representaciones artísticas y científicas? Consecuencias para una teoría general de la representación científica." *Análisis filosófico* 34:147–70.

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