**Scientific Representation and Understanding: A Communal and Dynamical View**

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Collin Rice

Colorado State University

corice@colostate.edu

**Abstract.** This chapter argues that both scientific representations and the understanding they produce are *communal* and *dynamic*. Specifically, it is argued that what a scientific theory or model represents can only be determined by looking at how the representation is used by communities of scientists over time. This contrasts with views that have appealed only to the current representational goals of individual model builders/users. It is also argued that scientific understanding is produced by communities of scientists using conflicting models, interests, and values over long periods of time. Consequently, accounts of scientific understanding need to move beyond the cognitive features of individual agents using individual models acting in isolation. As a result, accounts of scientific progress ought to show how diverse communities, using conflicting representations, can produce bodies of understanding across long spans of time.

**1. Introduction**

Numerous philosophers have recently focused on how various kinds of scientific representations are used to produce understanding of natural phenomena. In this chapter, I argue that both scientific representation and scientific understanding are *communal* and *dynamic*. That is, both are the products of larger groups of individuals interacting over long periods of time. As a result, in order to determine what a scientific model (or theory) represents and what it enables scientists to understand we must pay attention to the assumptions, interpretations, and goals of the broader scientific community and track how these contextual features change over time. For the purposes of this chapter, I will focus on scientific models as the paradigmatic example of scientific representation, and I will assume that most (if not all) models represent in some way. However, I contend that the communal and dynamical views I present here apply equal well to other kinds of scientific representations; e.g. theories or simulations.

While these claims might seem uncontroversial, as we will see, several philosophical accounts of what scientific models represent and how they produce understanding have focused on the interests, goals, and cognitive properties *of individuals* using particular models *in isolation*. For example, philosophers tend to analyze what features a given model represents simply by looking at what is claimed in the assumptions of the model and (perhaps) an individual modeler’s interpretation of which parts of the model are intended to accurately represent which features of the target system. It is then determined, based primarily on what the model accurately represents, what understanding can be acquired via the model.

In contrast, in Section 2, I argue that we can only determine what a scientific model represents by embedding it within a dynamical social context that includes the goals of the broader scientific community, the historical development of the model, and the various ways the model has been used in the past. In particular, I draw on resources from Ruth Millikan’s (1984, 1989) teleological account of representation to capture these social and historical features of scientific representation. Then, in Section 3, I argue that the production of scientific understanding also depends, in essential ways, on the communal/social and dynamical/historical aspects of scientific practice. Section 4 concludes by exploring some of the implications of these claims for how we ought to think about scientific progress.

**2. Scientific Representation: A Communal and Dynamical View**

The communal and dynamical view of representation I defend here contrasts with several views that have appealed primarily (or exclusively) to the mental states, goals, or purposes of individual model users/builders. For example, Craig Callender and Jonathan Cohen (2006) distinguish between fundamental and derivative representations as follows: “among the many sorts of representational entities…, the representational status of most of them is derivative from the representational status of a privileged core of representations” (2006, 70). They then argue that “scientific representation is just one more specific case of derivative representation” (2006, 75). The fundamental representations, on this ‘General Gricean’ view, are those studied by philosophy of mind: the mental states of individuals (2006, 71-74). In short, “the varied representational vehicles used in scientific settings… represent their targets… by virtue of the mental states of their makers/users” (2006, 75). Consequently, they argue that constructing a scientific representation “requires only an act of stipulation to connect representational vehicle with representational target” (2006, 79). In a similar way, Roman Frigg and James Nguyen suggest that scientific representations are generated when an agent, *A*, chooses an object as the base of the representation and then adopts a particular interpretation of what the model represents (2017, 169).

Rather than appealing to individuals’ stipulative fiats, Ronald Giere (2004) defends a similarity-based view of scientific representation that focuses on the *activity of representing* by analyzing how “*S* uses *X* to represent *W* for purposes *P*”(Giere 2004, 743). Giere then tells us that “*S* can be an individual scientist, a scientific group, or a larger scientific community” (2004, 743). Thus, in contrast with Callendar and Cohen, Giere’s view allows that the purposes of the larger scientific community might determine what a scientific model represents. However, Giere’s description of *S* suggests that the purposes of the larger scientific community are just one *optional* way to establish the content of a scientific representation. Thus, on Giere’s view, the purposes of an individual scientist will often be sufficient for creating a scientific representation.

Following Giere, Michael Weisberg’s (2007, 2013) view focuses on the model user’s *construal* to determine which similarities matter for evaluating the representational success of the model. Specifically, “The construal tells us which parts of the model correspond to parts of the real phenomenon and which parts can be ignored” (Weisberg 2007, 220). While Weisberg notes that communities often have standard conventions for how to interpret a model, he also suggests that individual modelers “make decisions about which aspects of their models are to be taken seriously. Their intended scope specifies which aspects of potential target phenomena are intended to be represented by the model” (Weisberg 2013, 40). Moreover, in other work, Weisberg tells us that the construal of the model “depends on the intentions of the model user” (Weisberg 2007, 221). Similarly, Peter Godfrey-Smith tells us that “two scientists might use the same model for the same target system, but with different resemblance relations in mind. I call these ‘construals’ of the model.” (2006, 733). Indeed, such appeals to the ‘goals of the modeler’ or the ‘aims of the model builder’ are widespread in the scientific modeling literature.

The above views all suggest that a (if not, the) primary determiner of the representational content of a model are the goals or purposes of the individual model builder/user. In contrast, I argue that mere stipulation, or construal, on the part of an individual scientist is insufficient for determining the content of a scientific representation. This is because only if the consumers of the model within the scientific community accept the proposed interpretation, assignment, or construal, will the model be able to contribute to accomplishing the aims of the scientific community. More specifically, I contend that the users that really matter for scientific representations are the broader scientific community that *consumes* the scientific representations rather than individual model builders that produce them. Consequently, the purposes that matter most are those of the broader scientific community rather than the purposes of the original model builder/user. In order to be a *scientific* representation, the model must be accepted by the larger scientific community and used for the purposes of that community. What the above accounts miss are the crucially important ways in which the background assumptions, goals, and interpretations of the scientific community both constrain and largely determine what a scientific representation represents. In other words, I propose that we need to replace Giere’s schema with the following:

C interprets X as a (scientific) representation of T for purposes P in social context S constrained by X’s history of use H within C.

Where C is a scientific community, group of scientists, or research program. X is a representational vehicle (e.g., a model, theory, physical object, computer simulation, etc.). T is a real or possible target system(s). P are the purposes or goals of the scientific community. S is the social context that includes the community’s background knowledge, goals, and values that determine which features are relevant and which can be ignored. And H is the set of historical uses of the representation within the community that furnishes conventions for interpreting the representation, the inferences/results it produces, and the justifications for various idealizing assumptions used within the representation. This schema makes explicit that it is scientific communities that interpret models and it is the purposes and histories of those communities that matter for determining the goals/purposes of a scientific representation. Rather than a special case, I argue that these communal and historical features play an essential role in determining the representational content of every scientific representation.

The communal and dynamical view I defend here incorporates several ideas present in Brandon Boesch’s critique of Callendar and Cohen’s view (Boesch 2017). In particular, Boesch notes that what Callendar and Cohen’s view misses are the communal aspects of how scientific representations obtain their content (Boesch 2017, 970). What is more, Boesch correctly notes that “Scientists do not merely start using a model however they like, without recourse to the history of the use of the model” (Boesch 2017, 978). Boesch goes on to argue that the importance of these communal and historical features of scientific representation is that they *license* scientists’ use of the model for scientific purposes such as answering questions about, explaining, or understanding a phenomenon (Boesch 2017, 978).

Despite these points of agreement, this chapter goes beyond Boesch’s view by analyzing in more detail some of the specific communal and dynamical aspects of scientific representations that enable them to play particular roles within scientific practice. Using Boesch’s terms, the view I present here aims to fill in the details of precisely which communal and dynamical features determine the content of scientific representations and license them to perform specific aims of science. In particular, while Boesch briefly mentions that scientific representations can be used to produce understanding, he does not discuss the particular ways that representation plays (or does not play) a role in allowing a model to produce understanding. In contrast, the relationship between representation and understanding (and its implications) are the focus of the later sections of this chapter.

In order to develop these general ideas a bit further, I propose an account of scientific representation based on Ruth Millikan’s teleological theory of representation (1984, 1989). While I don’t have the space to work through all the details of Millikan’s views here, a few general features of her account will prove particularly useful in capturing the social/communal and historical/dynamical aspects of scientific representation.

First, Millikan’s approach requires us to focus our attention on the *consumers* of representations rather than on their producers (Millikan 1989, 283). As Millikan explains: “Let us view the system, then, as divided into two parts or two aspects, one of which produces representations for the other to consume. *What we need to look at is the consumer part, at what it is to use a thing as a representation*” (Millikan 1989, 285, emphasis added). I suggest that because scientific communities are the consumers of scientific models and the results derived from them, it is the interpretations and goals of the broader community that we need to focus on to determine the representational content of a scientific model rather than the intentions of the individual producers of those models (whose interpretations or goals might run contrary to those of the broader community).

A second feature of Millikan’s view is that it requires us to consider the history of a representation (and the context in which it has been developed) in order to determine its content (Millikan 1984, 18; 1989, 284). Specifically, in order to determine the content of a representation, we need to determine its function, which is determined by its historical use. According to Millikan’s etiological view, the function of something is what earlier things of this type have done which has contributed to their survival and reproduction, which in turn explains their current use. In the case of representations (and removing the biological benefits involved in natural selection), this etiological view suggests that a representation means whatever earlier versions of the representation have been taken to mean (by the consumers) that has enabled them to positively contribute to the goals/aims/functions of the system in which those representations are used. This aspect of Millikan’s view helps us recognize that the historical development of a scientific representation and its past uses are essential for determining its current representational content.

A third feature of Millikan’s view is that the purposes/functions of a given representation are determined by the purposes of the larger producer-consumer system of which it is a part. In particular, the functions (or goals) that matter are the ways in which consumers use representations to generate benefits for the overall system (that includes both the producers and the consumers of those representations). In short, the etiological function of a representation is determined by the benefits its use (or the use of other similar/related representations) has provided for the overall system in the past.

In sum, Millikan’s view involves three crucial features that need to be incorporated into accounts of how scientific models represent:

1. The account focuses our attention on the interpretations, assumptions, and uses of *consumers* (rather than producers).
2. The account is *etiological/historical/dynamical* in that it focuses on the past uses and development of a representation to account for its representational content.
3. The account focuses our attention on *the goals/purposes/benefits of a larger system* that consumes/uses the representations to accomplish certain goals; i.e. the function of the representation is to produce certain benefits for the overall system.

Let’s apply these features of Millikan’s view specifically to scientific models. With respect to the first feature, I argue that the interpretations, background assumptions, and justifications adopted by the scientific community that uses/consumes a model are essential for determining what the model represents. Concerning the second feature, I propose that the content of a scientific model can only be determined by looking at the historical context and development of the model and the ways it has been interpreted/used in the past. It is the histories of a scientific model that tell us why a particular interpretation of its representational content has been adopted by the community. For novel models (or theories), I suggest that these contributions are made by the past uses of other similar (or related) representations, or the history of use of models and theories within the discipline or research program more generally. In short, looking at the historical uses of the model (and other related representations) enables us to determine what the model has been taken to represent that has enabled it (or other related representations) to contribute to the aims of scientific inquiry. Moreover, I contend that these historical aspects make important contributions to the representational content of a model even if current scientists have different representational aims. Users’ current aims will certainly contribute something as well, but what the model represents for the scientific community cannot be isolated from its history of uses and interpretations. Finally, concerning the third feature, I suggest that the goals/purposes/functions that matter most for determining what a scientific model represents are the benefits provided for the broader scientific community rather than individual model builders/users. In sum, what the model represents is largely determined by what the community of scientists has taken that model to represent (both accurately and inaccurately) that has led to its past production of benefits for the scientific community; e.g. predictions, explanations, or understanding. The production of these benefits for the community then results in the representation (and its interpretation) being copied/reused in later scientific work. Indeed, given that the broader community determines what the aims of science are and the standards for evaluating when they have been achieved, what makes a representation a *scientific* representation is that it is designed to be consumed by the scientific community so as to achieve the goals of that community.

Putting these pieces together, I contend that consideration of each of the following five components is necessary to determine the representational content of a scientific model (this list is not intended to be exhaustive):

1. The beliefs, interpretations, and goals of the model builder/user (the producers)
2. The beliefs, interpretations, and goals of the larger scientific community (the consumers)
3. Background assumptions furnished by science’s best current (and past) scientific theories (these influence how a model is built, used, and interpreted by the community)
4. The community’s understanding furnished by other models (these beliefs partially constitute the social context in which the model is interpreted/used by the community)
5. Justifications provided for past uses of idealizations within the model (this clarifies the reasons why the model has been used in the past that justify its continued use in certain contexts)

What this list shows is that, while the beliefs and goals of an individual model builder/user are part of the story, they are nowhere near sufficient for determining the representational content of a scientific model (or theory). Only by placing the model and its user(s) within a larger social and historical context will we be able to determine what it represents. While some of representational content will be determined by the representational aims of current users, many parts of that content will be fixed (or heavily constrained) by past interpretations and uses of the model (or other similar models).

Since other philosophers have described the ways the model builder’s intentions can contribute to a model’s representational content, I’ll begin by looking at the beliefs, interpretations, and goals of the larger scientific community. First, as Weisberg notes, “communities of modelers have standard conventions for reading model descriptions” (2013, 40). Indeed, scientific communities routinely adopt various rules and conventions about how a given (type of) model ought to be interpreted, justified, or used. What is more, these conventions often provide what Christopher Pincock refers to as ‘anchors’ that link mathematical models to their target systems in specific ways and can structure entire research programs (2012, 492). Consequently, the representational content of a scientific model is typically partially determined, and thereby highly constrained, by the interpretations, assignments, and conventions adopted by the communities that use the model for a variety of scientific purposes. Of course, the particular goals of individual model builders/users will certainly have *some* role to play here. For example, what the modeler is interested in might determine which communities of scientists they take their target audience to be and which types of models they choose to develop. Nonetheless, because the scientific community adopts particular conventions for interpreting and using certain models, an individual scientist is limited in the ways they can stipulate, construe, or map their models onto their targets and still have the model accomplish its purposes within the larger community.

The next feature of the scientific community that partially determines the content of a scientific model are the modeling assumptions it incorporates from the community’s best theories (both past and present). As Giere (and others) have noted, scientific theories often provide ‘general principles’ that “act as general templates for the construction of more specific abstract objects that I would call ‘models’” (2004, 745). In addition, scientific theories will often furnish various assumptions about what is relevant or irrelevant to the phenomenon. For example, the kinetic theory of gases tells us that what is relevant for understanding changes in gas behavior are the macroscale averages of the system (e.g. its mean kinetic energy) and that the particular motions and locations of the individual particles are irrelevant. As a result, the scientific community in which various gas models are formulated implicitly assumes that the overall statistical properties of the system (e.g., its pressure and temperature) are what the model aims to represent about real gases and that the motions and interactions of individual particles are not part of what the model aims to (accurately) represent. In short, the construal that specifies which parts of the model ought to be interpreted as relevant and which ought to be ignored is heavily influenced by the theories the scientific community has adopted.

Within a particular community (or research program), another feature that determines the representational content of a scientific model is the understanding furnished by results derived from other models. We might call this the community’s ‘background knowledge’ into which both the model, its interpretation, and its results are embedded (Weisberg 2013, 135). For example, a modeler in cognitive science might choose to model (and measure) certain areas of the brain due to previous studies demonstrating the role those regions play in producing the behaviors of interest. This can also happen across scientific disciplines, e.g., when economic modelers incorporate information from evolutionary biology concerning the features of human cognition (Rice and Smart 2011). Thus, it isn’t just the history and development of a particular model that helps determine its representational content, but also the history, development and understanding produced by other models (and theories) that furnish various assumptions or parameter values used for constructing and interpreting the model. Consequently, what a model is taken to represent depends heavily on the community’s current state of scientific understanding.

Finally, one of the ways the community helps determine the representational content of a scientific model is by providing justifications for the use of various idealizing assumptions employed within the model. Indeed, many idealizing assumptions that are repeatedly reused within a research program are justified by the modeling results of previous scientists (Pincock 2012). Moreover, the ways these idealizations are interpreted and justified are often carried along with the model across different applications (or contexts) that depend on the ways in which the model has been developed, used, and understood by the broader scientific community (Knuuttila and Loettgers 2014; Rice and Smart 2011).

The features briefly surveyed here show why the history, purposes, interpretations, and uses of the larger scientific community are absolutely essential for determining what a scientific model (or theory) represents. What is more, the above view provides a clear way to demarcate scientific representations from non-scientific representations. These representations are scientific representations because they are developed within the social/historical context of a scientific community for the purposes/goals of that community. The above features also show that what a model represents can change as different theories, assumptions, interpretations and goals are adopted by the scientific community. Indeed, as Weisberg notes, “Modelers might initially deem some features of models and targets important, but, as science progresses, these might be judged to be irrelevant. Similarly, new properties of targets might come to be recognized as especially important. These changes in practice and interest will occasion…a reevaluation of the model-world relationship” (Weisberg 2013, 149). This entails that scientific representation is inherently dynamic (rather than static). Finally, given that the features discussed above can be realized in multiple different ways, there is plenty of room in this view for pluralism about the kinds of things that represent (e.g., mathematical equations, physical objects, or computations), what they represent (e.g., real or possible systems), and how their content is specifically determined within different research programs. Despite this variety, in each case, what a scientific model (or theory) represents will essentially depend on the history, assumptions, interests, and goals of the broader scientific community. Moreover, as those features of the community change, so will the representational content of the model (or theory). Therefore, scientific representation is both communal and dynamic.

**3. Scientific Understanding: A Communal and Dynamical View**

Similar to the above account of scientific representation, in this section I argue that philosophical accounts of scientific *understanding* need to move beyond their focus on the cognitive states of individuals and the representational capacities of individual models and, instead, must consider the conditions required for scientific communities (i.e., groups) to understand natural phenomena via multiple conflicting models used at different points in the history of science.

 To see why this shift is important, it is worth noting that many accounts of scientific understanding have appealed to the mental states or cognitive limitations of individuals. A primary reason for this is because much of the epistemology literature concerning understanding has sought to determine how individual agents understand and how that cognitive state differs from knowing (Grimm 2006; Khalifa 2017; Pritchard 2009; Zagzebski 2001). As a result, following the literature on knowledge, philosophers writing about understanding routinely adopt a definition that begins with ‘*S* understands *p* if and only if…’, where *S* is an individual agent and what comes after the ‘if and only if’ specifies the conditions that must be met for that agent to understand. Furthermore, some epistemologists have explicitly denied that the etiological aspects of understanding are important. For example, Jonathan Kvanvig argues that “Understanding does not advert to the etiological aspects which can be crucial for knowledge. What is distinctive about understanding, once we have satisfied the truth requirement, is internal to cognition” (2003, 198-9).

Philosophers of science, too, have routinely appealed to the cognitive states of individuals in order to analyze scientific understanding (e.g. see Khalifa 2017; Potochnik 2017; Strevens 2013).[[1]](#footnote-1) As an example, following Sandra Mitchell (2012), Bill Wimsatt (2007), and others, Angela Potochnik argues that the reason scientists need to use idealizations to understand natural phenomena is because the causal complexity of the world greatly outstrips what our limited minds can comprehend (Potochnik 2017, 1-2). This approach to idealization, and its role in generating understanding, implies that what science can understand is largely determined by what individual scientists are able to grasp. Indeed, Potochnik tells us that “Scientific understanding is generated via the production of scientific explanations. Successful explanation explicitly depends on the features of human psychology and cognition as much as it depends on features of the world” (Potochnik 2017, 20). More specifically, Potochnik appeals to the cognitive psychology literature to argue that agents (scientifically) understand by grasping general patterns that are based on causal relationships (Potochnik 2017, 113-114). Indeed, several philosophers have argued that the features of individuals’ psychology provide insights into the nature of scientific understanding.

A final way philosophers have tied scientific understanding to the cognitive states of individuals is by arguing that in order to scientifically understand a phenomenon an individual must grasp an explanation of that phenomenon. For example, Michael Strevens and J. D. Trout both argue that an individual has scientific understanding of a phenomenon just in case they grasp a correctscientific explanation of that phenomenon (Strevens 2013, 510; Trout 2007, 585-86). Even those accounts that claim there can be understanding without explanation have largely focused on the understanding of individuals (Lipton 2009; Rohwer and Rice 2013).

In addition, most accounts of how scientific models enable scientists to understand have appealed to the relatively static representational capacities of individual models. In particular, most philosophers suggest that whether or not a scientific model is able to produce understanding depends primarily on what the model accurately represents, captures, or exemplifies (e.g. see Elgin 2017; Potochnik 2017; Strevens 2013; Weisberg 2013). This implies that what scientific understanding can be produced via a given model is largely determined by the representational capacities (or accuracy) of that particular model.

While there are certainly important epistemological questions about how individuals understand via individual models, I contend that this focus has forced philosophers to miss two of the most distinctive aspects of *scientific* understanding. First, scientific understanding is produced by, and codified within, scientific communities that are composed of diverse individuals with different experiences, values, background assumptions, and goals. What is more, the understanding produced by these scientific communities almost always depends on various interactions among diverse members of the community that enable the scientific community’s understanding *to go well beyond what could be grasped by any individual scientist.* Consequently, appealing only to the cognitive states and limitations of individuals misses the distinctively communal methods science uses to produce understanding. Second, a scientific community’s understanding of a natural phenomenon is typically produced via the use of multiple conflicting representations over relatively long spans of time. As a result, scientific understanding is essentially a diachronic phenomenon that cannot be analyzed merely by looking at the representational capacities of a single model (or theory) in isolation.

Following several other accounts in the literature (Le Bihan 2017; Grimm 2006; Rice 2016; Saatsi 2019; Woodward 2003) I suggest that the kind of information that produces scientific understanding of a phenomenon is modal information about how the phenomenon would (or would not) change in various counterfactual situations. In other words, scientific models produce understanding by enabling scientific communities to answer a range of what-if-things-had-been-different questions. This idea is derived from various accounts of scientific explanation that appeal to the outcomes of interventions (Woodward 2003). However, I see no reason to restrict the modal information that constitutes a scientific community’s understanding to information about the results of interventions. Instead, I suggest that scientific understanding can also be deepened by grasping what would be the case in very distant counterfactual situations that tell us little about the actual features of real-world systems, or how intervening on those features would change the system (Rice 2021). I do not have the space to lay out all the details of this modal account or a full defense of all its features. However, I aim to show that adopting a modal approach to scientific understanding enables us to capture crucial aspects of both the communal/social and dynamical/historical ways that science produces understanding.

Let’s begin with the communal aspects of scientific understanding. It is crucial to note that scientific understanding is only produced via a model when scientists employ their experiences, values, background assumptions and goals to interpret, interact and *use* a model for particular purposes. Merely determining the representational capacities of the model is insufficient for determining the ways that these uses/interactions generate understanding. Moreover, since different scientists will bring different background assumptions, interests, and values to their interactions with the model (and the larger scientific community), different scientists will be able to extract different sets of modal information from a given scientific model. As Henk de Regt notes, when scientists engage with scientific representations, their “preferences are related to their skills, acquired by training and experience, and to other contextual factors such as their background knowledge, metaphysical commitments, and the virtues of already entrenched theories.” (2009, 592). The key point I want to emphasize here is that these contextual values, skills, training, experience, background knowledge, metaphysical commitments, etc. are all heavily influenced and constrained by the broader scientific community. In other words, these important features of the ways that different scientists interact with their models are part of a much larger social (and historical) context (de Regt and Dieks 2005). Furthermore, it is *the interactions between* different members of the larger scientific community that integrates these various pieces of modal information into a body of information that constitutes the scientific community’s overall understanding of a natural phenomenon. Crucially, this set of modal information will (almost always) go well beyond the set of modal information that is grasped—or is graspable—by any individual scientist. In short, only by looking at the social context that structures the ways scientists use their models and how they interact with one another can we determine what the scientific community is able to understand via a given (set of) model(s).

What is more, in contrast with views that analyze scientific understanding via accurate representation of the actual world, a modal account of scientific understanding easily accommodates the epistemic contributions made by groups of scientists using multiple conflicting models in order to understand the same phenomenon (see Chakravartty 2010, Morrison 2011, or Weisberg 2013 for some examples). Specifically, different models can be used to explore different counterfactual situations that are of interest to different modelers within the community. For example, one group of scientists might use a model focused on genetic factors to determine what would happen in various situations where those factors are changed and environmental factors are absent. Another group of scientists (with different interests and goals) might use a scientific model that makes fundamentally different assumptions and idealizations to explore counterfactual situations in which various environmental factors are changed and genetics is largely ignored (or held fixed). In short, different groups of scientists will use different (and often conflicting) idealized models to answer the what-if-things-had-been-different questions that are of interest to them. The counterfactual information used to answer these questions can then be combined via various interactions among the members of the scientific community—even if no individual scientist is interested in, or able to grasp, all of the counterfactual information that constitutes the community’s overall understanding of the phenomenon.

Considering the role of modal information in scientific understanding also enables us to capture the etiological/historical aspects of the processes by which science produces understanding. First, we should remember that the interests, assumptions, and interpretations of the scientific community can change over time. This means that scientists will be interested in using their models to explore different counterfactual situations as different what-if-things-had-been-different questions become interesting to them. For example, looking at the history and development of a scientific model will enable us to see how scientists’ background assumptions about what is relevant/irrelevant to the phenomenon of interest have influenced which pieces of modal information they investigate with their models. As science progresses, the same model might be used to extract very different pieces of modal information as the uses, interpretations, and goals of the scientific community (or research program) changes. Therefore, what understanding a given scientific model provides cannot be determined synchronically by looking just at what a model represents at a particular time.

The second etiological/historical aspect of scientific understanding involves the contributions of past models and theories. These representations have been disconfirmed/replaced and are typically in conflict with the representations currently adopted by the scientific community. Nonetheless, I suggest that much of the understanding that a scientific community has regarding a phenomenon is derived from these past scientific representations. For example, despite being replaced by alternative theories during the modern synthesis, much of our current understanding of biological traits has been derived from Darwin’s original theory of selection. Similarly, Bohr’s model of the hydrogen atom has greatly contributed to the scientific community’s understanding of atoms despite being replaced by later quantum mechanical models (Bokulich 2011). One way to account for the understanding produced by these past theories and models is to note that learning about counterfactual situations—including rather distant possible worlds—can improve (or deepen) scientists’ understanding of a phenomenon. Consequently, past representations can contribute to scientific understanding by providing (true) modal information about what would happen in various counterfactual situations.

In summary, scientific understanding of a phenomenon is not accomplished by a single modeler using a single model in isolation. Only by considering how diverse communities of scientists interact over time to develop bodies of understanding via the use of multiple (potentially conflicting) representations can we capture the essential features of *scientific* understanding.

**4. Representation, Understanding, and Scientific Progress**

Although both scientific representation and scientific understanding are communal and dynamic, I contend that the understanding a scientific model is able to produce for a community is largely independent of whether it accurately represents the relevant or interesting features of its target systems (Rice 2021). This suggestion runs contrary to several views that have suggested that scientific understanding is produced by accurately representing the difference makers for the phenomenon (e.g. Strevens 2008, 2013). There are several reasons accounts of scientific understanding ought to move beyond such appeals to accurate representation (or instantiation) relations:

1. Much of science’s understanding is produced via idealized models that directly distort features that are known to make a difference and are of interest to the scientists using the model (Rice 2017, 2018).
2. Scientific models that tell us about merely possible systems can greatly improve scientific understanding (Le Bihan 2017; Rice 2021; Saatsi 2019).
3. Much of science’s current understanding of phenomena has been derived from past scientific representations that are known to be inaccurate and are in conflict with our current models/theories of those phenomena (Bokulich 2008; Potochnik 2017; Rice 2021; Saatsi 2019).
4. Science often produces understanding via the use of multiple conflicting models for the same phenomenon (Chakravartty 2010; Elgin 2017; Morrison 2011; Potochnik 2017; Rice 2021).

These observations about scientific practice provide strong reasons for thinking that what a community is able to understand does not depend on the representational accuracy of the models it uses to produce that understanding. Furthermore, they suggest that producing more accurate representations will not necessarily produce more understanding. Rather, given the modal nature of scientific understanding, producing large sets of incompatible models (many of which may distort the difference-making features of interest) will typically produce a deeper understanding of a phenomenon than developing representations that accurately represent different aspects of the phenomenon in consistent ways. What is more, in contrast with realists’ suggestion that science makes progress by constructing ever-more accurate representations of real systems, I contend that science makes progress by evolving towards the development of (sets of) representations that are progressively *more* *useful for producing understanding*. Consequently, science makes progress by developing (conflicting) sets of representations that expand and deepen the community’s understanding of natural phenomena.

I have argued that incorporating these communal and dynamical features of scientific practice is necessary for capturing the essential (though not unique) features of scientificrepresentation and understanding. Only by incorporating these features will philosophers be able to generate accounts of these concepts that more accurately describe the ways that evolving scientific communities construct multiple conflicting representations in order to understand natural phenomena.

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1. In fact, philosophers of science often assert that scientific understanding just is a species of knowledge (Salmon 1989; Woodward 2003). [↑](#footnote-ref-1)