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Understanding realism

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Abstract. Catherine Elgin has recently argued that a nonfactive conception of understanding is required to accommodate the epistemic successes of science that make essential use of idealizations and models. In this paper, I argue that the fact that our best scientific models and theories are pervasively inaccurate representations can be made compatible with a more nuanced form of scientific realism that I call *Understanding Realism*. According to this view, science aims at (and often achieves) factive scientific understanding of natural phenomena. I contend that this factive scientific understanding is provided by grasping a set of true modal information about the phenomenon of interest. Furthermore, contrary to Elgin's view, I argue that the facticity of this kind of scientific understanding can be separated from the inaccuracy of the models and theories used to produce it.

1. Introduction

Both philosophers of science and epistemologists have recently focused on the question of how idealized scientific models can produce understanding (de Regt, Leonelli and Eigner 2009; Elgin 2017; Khalifa 2013, 2017; Kvanvig 2003; Mizrahi 2012; Potochnik 2017; Rice 2016; Schurz and Lambert 1994; Strevens 2013). For example, in her new book *True Enough*, Catherine Elgin argues that a nonfactive conception of understanding is required to accommodate the epistemic achievements of science that make essential use of idealizations (Elgin 2017). In this paper, I argue that the fact that our best scientific models and theories are pervasive distortions of real systems can be made compatible with a more nuanced form of scientific realism that I call *Understanding Realism*. The key to Understanding Realism is shifting realist views of science away from focusing on whether scientific representations accurately represent relevant (e.g. difference-making) features towards a defense of the facticity (or accuracy) of the understanding that can be produced by using idealized theories and models in strategic ways.

Philosophical discussions of scientific realism frequently focus exclusively on the truth or accuracy of models or theories themselves rather than the truth, accuracy, or justification of the body of scientific understanding produced by scientists' use of those models and theories. I contend that this focus is far too narrow for adequately evaluating the prospects for scientific realism. Unfortunately, the debate over realism has been so focused on the truth and continuity of (parts of) scientific theories that it has failed to even consider alternative ways that the required truth and continuity might be achieved by scientific inquiry.

In order to move beyond traditional ways of framing the realism debate, I will grant that our best scientific models and theories are pervasive misrepresentations of their real-world target systems (Elgin 2017; Morrison 2015; Potochnik 2017; Rice 2017, 2018). That is, in agreement with Elgin, I will grant that the representations produced by scientific inquiry are not true and do not purport to be true (Elgin 2007, 2009, 2017). However, in contrast with Elgin, I then argue that *factive* understanding is the primary epistemic goal of science and that this epistemic achievement can be, and often is, accomplished by investigating and manipulating idealized models and theories that fail to accurately represent the relevant features of their target systems (Rice 2016).[1] In order to appreciate how this could be so, philosophers must *look at the information that scientific communities extract from highly idealized models*; e.g. by manipulating and combining multiple models in various ways to discover modal information about possible states of the system(s) of interest.

The following section draws out several mistaken assumptions that have dominated the realism debate. Removing these assumptions makes room for a form of realism that is compatible with our best models and theories being pervasively inaccurate representations. Next,

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[1] I do not claim that understanding is the only aim of science. I only claim that it is the primary epistemic aim that realists should be concerned with.

Section 3 lays out a factive account of scientific understanding in terms of providing correct modal information about the phenomenon. Section 4 provides examples that demonstrate how pervasively distorted models can be used to produce this kind of factive understanding. Then, Section 5 explicitly lays out my Understanding Realism view. The final section concludes and suggests that philosophers look more directly at the factive understanding produced by scientific communities rather than focusing on the accuracy (or facticity) of the scientific representations used to produce that understanding.

2. Realism, Accurate Representation, and Idealization

Traditionally, scientific realism claims that science aims at truth and that we have reason to believe that our most successful scientific theories and models are true or approximately true descriptions of the natural world (Kitcher 1993; Putnam 1975; Psillos 1999; Stanford 2006; van Fraassen 1980). The main argument for realism—the so called 'No Miracles Argument'—argues that we are justified in believing our best scientific theories are accurate because this is the best (or only) explanation of their ability to yield many successful predictions and interventions (Putnam 1975). However, as opponents of realism have repeatedly argued, the history of science shows that previously believed, but ultimately inaccurate theories, have also made accurate predictions (Laudan 1981; Stanford 2006; van Fraassen 1980). What is more, several philosophers have suggested that science's widespread use of idealizations raises additional problems for the realist (Cartwright 1983; McMullin 1985; Odenbaugh 2011; Psillos 2011; Suárez 1999). The argument runs roughly as follows: given that we know scientific representations include false assumptions, even if they make accurate predictions, we have no reason to believe that they are true (or accurate) (see Odenbaugh 2011 for an example).

These observations undermine the main argument that has been given for realism, but they also perform another unintended function: they show that inaccurate models and theories can accomplish many of the goals of science (Elgin 2017; Potochnik 2017; Strevens 2008; Weisberg 2013). My thesis is that, in addition to being useful for prediction, pervasively idealized models and theories can be used to produce *factive understanding* of real phenomena. Moreover, I will argue that it is within these epistemic achievements that the truth or accuracy the realist seeks is to be found rather than within the (partially) accurate representations of scientific models or theories themselves. That is, we can be realists about the epistemic achievements of scientific practice while granting that our best models and theories are pervasively inaccurate descriptions of reality.

There are two main reasons this possibility has yet to be adequately explored. First, as I noted above, the realism debate has been exclusively focused on the truth of scientific models and theories *themselves* rather than on the corpus of understanding that scientific communities can acquire from using idealized models and theories in strategic ways.[2] A second reason this possibility has yet to be adequately explored is that, throughout the literature, it is assumed that the primary way that science produces understanding is by providing explanations (Friedman 1974; Salmon 1984; Strevens 2008). This claim is then coupled with the fact that most accounts of explanation involve truth or accuracy requirements in order to conclude that the representations scientists use to understand natural phenomena must be (at least partially) accurate (de Regt and Gijsbers 2017).[3]

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[2] An important exception here is Potochnik (2017) that focuses on the way that diverse communities focused on different causal patterns can produce understanding. However, Potochnik's discussion never really addresses the realism debate and, in contrast with the view I defend here, she argues that the understanding produced by science is nonfactive.

[3] Bas van Fraassen nicely summarizes this realist line of argument: "Science aims to find explanation, but nothing is an explanation unless it is true (explanation requires true premises); so science aims to find true theories about what the world is like. Hence scientific realism is correct" (van Fraassen 1980, 97). van Fraassen, of course, goes on to

Indeed, ever since Hempel (1965) required that the propositions in the explanans be true, most accounts have maintained that explanations must accurately describe the explanatorily relevant features responsible for the explanandum. For example, mechanistic accounts of explanation often endorse some kind of 'model to mechanisms mapping' requirement for models to explain (Craver 2006; Craver and Darden 2013; Kaplan and Craver 2011). These accounts then respond to the widespread use of idealization in science by suggesting that this observation,

> […] should not lead one to dispense with the idea that models can more or less accurately represent features of the mechanism in the case at hand…These practices of abstraction and idealization sit comfortably with the realist objectives of a mechanistic science. (Kaplan and Craver 2011, 610)

In other words, we can respond to challenges to realism from idealization by showing that idealized models can still provide *partially accurate representations* of their target mechanism(s).[4]

Most causal accounts also build in accuracy requirements for models to explain. As Michael Strevens puts it, "no causal account of explanation—certainly not the kairetic account— allows nonveridical models to explain" (Strevens 2008, 297). While Strevens's account does allow some idealized models to explain, accurate representation continues to play a key role since, "the overlap between an idealized model and reality...is a standalone set of difference-makers for the target" (Strevens 2008, 318). More generally, for causal accounts, in order for a model to explain it must provide an accurate representation of (at least some of) the difference-making causal relationships within the target system(s).

In light of these accurate representation requirements for explanation, most philosophers have also maintained a factive (or veridicality) requirement for scientific understanding (de Regt

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deny that in order to explain a theory must be true, but he is correct in characterizing the standard *realist* reasoning as requiring that explanations be provided by true theories (or models).

[4] More generally, for mechanistic accounts, "the goal is to describe correctly enough (to model or mirror more or less accurately) the relevant aspects of the mechanisms under investigation" (Craver and Darden 2013, 94).

2009; de Regt and Gijsbers 2017; Grimm 2008; Mizrahi 2012; Khalifa 2012, 2017; Kvanvig 2003, 2009; Strevens 2013). In fact, several philosophers have argued that scientific understanding is *only* produced by grasping a correct explanation. For example, Strevens follows J.D. Trout (2007) in claiming that, "An individual has scientific understanding of a phenomenon just in case they grasp a *correct* scientific explanation of that phenomenon" (Strevens 2008, 3; 2013, 510). In addition, Jonathan Kvanvig tells us that, "understanding why something is the case requires understanding that a certain explanation is correct" (Kvanvig 2003, 189-90).[5]

In general, most philosophical accounts claim that for idealized models to provide genuine understanding (often by providing an explanation), the model must accurately represent the important, significant, or difference-making features of the system that actually produced the phenomenon of interest. These accurate representation requirements, however, conflict with the observation that most of the idealized models used to explain and understand in science *pervasively distort* their target systems—including the features that scientists know make a difference to the phenomenon (Batterman and Rice 2014; Longino 2013; Potochnik 2017; Rice 2017, 2018). For example, models in physics distort the difference-making components and interactions of fluids, magnets, and quantum dots (Batterman 2002; Batterman and Rice 2014; Bokulich 2012; Morrison 2015), models in biology distort the difference-making processes of drift and selection (Ariew et al. 2015; Morrison 2015; Potochnik 2017; Rice 2013, 2018), models in economics distort the difference-making features of agents and transactions (Frigg 2010; Knuuttila 2009), models in the study of human behavior distort difference-making genes and environmental factors (Longino 2013), etc. The more general problem is that most of the

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[5] Moreover, Kvanvig claims that a key relationship between knowledge and understanding "is that both imply truth, that both are factives. To say that a person understands that *p* therefore requires that *p* is true" (Kvanvig 2003, 190). Stephen Grimm also suggests that, "our understanding of natural phenomena seems conspicuously *factive*—what we are trying to grasp is how things actually stand in the world" (Grimm 2006, 518).

idealizations used in scientific practice cannot be quarantined (or separated) from the parts of science that are responsible for science's epistemic successes (Elgin 2007, 2009, 2017; Potochnik 2017; Rice 2018). As a result, the accurate representation relations that are required by most realist approaches to science will fail to hold in most actual cases—even if we focus only on known difference makers.[6]

What is more, very often in science we find multiple *conflicting* idealized models being used to explain and understand the same phenomenon (Morrison 2011; Massimi 2018; Rice 2019; Weisberg 2013). When this occurs, a different, but related, epistemological problem arises for the realist. In particular, if the realist is committed to endorsing the idea that the models scientists use to understand must be accurate representations of difference makers, then these uses of multiple conflicting models would seem to lead to the endorsement of inconsistent metaphysical claims or the denial that such modeling can produce genuine understanding (Massimi 2018; Rice 2019).[7]

I contend that realist approaches to science will continue to fall prey to the challenges raised by pervasive idealization and the use of multiple conflicting models as long as philosophical accounts continue to conflate the following two questions:

(1) How does the scientific model (or theory) allow scientists to *genuinely understand* (perhaps by explaining) the phenomenon?

(2) Which of the relevant features (e.g. difference making causes) for the occurrence of the phenomenon are *accurately represented* by the scientific model (or theory)?

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[6] As Markus Eronon and Raphael van Reil summarize the challenge: "On the one hand, understanding provided by scientific models seems to be genuine understanding, but on the other hand, it often seems to be non-factive, as the models involved are known to be literally false." (Eronon and van Reil 2015, 3777).

[7] Indeed, Michela Massimi (2018) has recently argued that the supposed incompatibility of the use of multiple inconsistent models and realism depends on the implicit assumptions that the goal of modeling is "to establish a one-to-one mapping between relevant (partial) features of the model and relevant (partial) — actual or fictional — states of affairs about the target system" (Massimi 2018, 342).

In short, the problem is equating science's understanding of a phenomenon with a model or theory's accurate representation of relevant features due to the truth and accuracy requirements maintained by most accounts of explanation and understanding.

In contrast with these attempts to show that scientific understanding is factive, Elgin (2007, 2017) argues that the pervasive use of idealizations shows us that only a nonfactive conception of understanding can accommodate the epistemic achievements of science. On Elgin's view, "Effective models afford an understanding of their targets because their simplifications, idealizations, elaborations, and distortions make salient important features of the targets" (Elgin 2017, 249). Elgin's justification for believing that idealized models are able to produce nonfactive understanding relies heavily on the concept of *exemplification*. Exemplification is a kind of instantiation of properties of the target system: "To exemplify, an item must refer to the feature in question, and must do so via its instantiation of that feature" (Elgin 2017, 185). Consequently, on Elgin's account, "Idealizations are fictions expressly designed to highlight subtle or obscure matters of fact. They do so by exemplifying features they share with the facts" (Elgin 2007, 39). The crucial question is just how far of a departure this is from the views described above given that exemplification still requires the model to share key properties with real systems in order to generate understanding. In what follows, I disagree with Elgin that being able to instantiate or approximate important features via exemplification is the only way that models make features salient for purposes of understanding. While a scientific model certainly "equips us to see the target differently than we otherwise might" (Elgin 2017, 263), this is often accomplished without regard to whether or not the salient features are exemplified, instantiated, or accurately represented within the model. Moreover, I will argue that the pervasive use of idealizations within scientific representations need not force us to adopt a

nonfactive account of scientific understanding. As we will see below, by separating scientific models (and theories) from the understanding scientists acquire by using those representations we can see how inaccurate scientific representations can be used to improve our understanding—*even if we maintain factive requirements for understanding*. First, however, we need an account of the epistemic achievement of factive understanding.

3. Factive Understanding and Modal information

Within the epistemology literature, one of the main ways that understanding is distinguished from knowledge is that, while knowledge seems to apply to individual propositions, understanding is a cognitive relation to more extensive 'bodies of information' (Elgin 2007, 2017; Kvanvig 2003; Grimm 2006). As Kvanvig puts it, "Understanding requires the grasping of explanatory and other coherence-making relationships in a large and comprehensive body of information. One can know many unrelated pieces of information, but understanding is achieved only when informational items are pieced together by the subject in question" (Kvanvig 2003, 192). Elgin agrees: "understanding is primarily a cognitive relation to a fairly comprehensive, coherent body of information" (Elgin 2007, 35). For example, when we say that a person understands the motion of the planets, they must grasp a fairly comprehensive body of information about the planets along with various relationships between those pieces of information.

In addition, the information and relations grasped about a phenomenon must be incorporated into a larger body of information. Elgin puts the point this way: "The understanding encapsulated in individual propositions derives from an understanding of larger bodies of information that include those propositions." (Elgin 2007, 35). Philosophers of science also

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suggest that "to understand a phenomenon *P* is to know how *P* fits into one's background knowledge" (Schurz and Lambert 1994, 67). In other words, in order to understand, an agent needs to not only grasp various relations among the components of a body of information, but those connections must also enable the agent to incorporate that information into their wider set of background knowledge. Following these views, on the account I present here, scientific understanding of a phenomenon requires that what one believes about the phenomenon, and the relationships between those beliefs, must be systematically integrated into a wider body of background information. Therefore, in order to understand a phenomenon, an agent must (1) grasp the relations between a fairly comprehensive body of information about the phenomenon and (2) see how that information is related to various pieces of their background knowledge. Grasping these systematic relationships between information about the phenomenon (and one's other beliefs) is the 'something further' that must be grasped in order to genuinely understand. This point about incorporation is important because it shows why scientific models are unable to provide understanding in isolation.[8] Instead, the information extracted from scientific models by using them in various ways must also be incorporated into the scientist's or the scientific community's overall body of information about the phenomenon.

The next question is, of course, just what information and relations must one grasp in order to understand a phenomenon? I suggest that the primary source of scientific understanding comes from grasping relationships of counterfactual dependence and independence among various observable and unobservable features of the system and the phenomenon of interest (Rice 2016, 2019). That is, understanding requires that one have a certain body of justified true beliefs about the subject matter *and be able to answer a range of what-if-things-had-been-*

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[8] Thanks to an anonymous reviewer for pushing me to make this point clearer.

different questions concerning changes to the features of the system(s) (Grimm 2006; Woodward

2003)*.* In order to grasp these counterfactual dependencies and independencies, we need to see

how changes to the features of the system do or do not change the phenomenon of interest. This

requires that we have some sense of the modal space of possibilities and how the phenomenon

changes across that space.[9] Providing accurate information about the phenomenon across a range

of possible situations shows us which features of the system are important (and unimportant) for

producing the phenomenon in the actual case—i.e. counterfactual information provides

information about the actual dependencies and independencies that hold in real systems.

However, we can only see these counterfactual dependencies and independencies by evaluating

contrastive situations where those feature are different. Consequently, I argue that the relevant

kind of relations that must be grasped within a coherent body of information in order to

scientifically understand a phenomenon are relationships of counterfactual dependence and

independence between features of the system and the phenomenon of interest. For example,

understanding planetary motion requires that one have a set of justified true beliefs about how

planets move and that one grasp how things would have been different had those facts been

different in various possible ways; e.g. had the earth had a much smaller mass. By grasping what

would occur in various counterfactual situations, scientists come to understand which features of

the system are important to the occurrence of the phenomenon and how the phenomenon

depends on those features.

One reason to focus on the modal information involved in understanding is that, while

explanations and understanding are importantly distinct (Lipton 2009; Rohwer and Rice 2016),

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[9] Soazig Le Bihan explicates this idea in more detail in terms of knowing "how to navigate some of the possibility space associated with the phenomena (Le Bihan 2017, 112). Much of what follows is in agreement with that view although I focus more on how idealized scientific models can provide the kind of modal information required to understand.

the primary way science produces understanding is by developing explanations (Friedman 1974; Salmon 1984; Strevens 2008). Consequently, the kind of information required for understanding ought to be closely related to the information provided by scientific explanations. Indeed, as Elgin notes, scientific understanding of natural phenomena "is the conception of understanding that is closely connected with explanation" (Elgin 2007, 35).

Although I will not be arguing for any particular account of explanation here, it is widely accepted that an important aspect of scientific explanations is that they provide a set of modal information about how the features of the explanans relate to the explanandum (Bokulich 2008; Craver 2007; Potochnik 2017; Rice 2013; Strevens 2008; Woodward 2003). Indeed, information about counterfactual dependencies that hold in the system features prominently in causal accounts of explanation (Potochnik 2017; Woodward 2003), noncausal accounts of explanation (Reutlinger 2016; Rice 2013), statistical accounts of explanation (Ariew et al. 2015), and structural accounts of explanation (Bokulich 2008, 2011, 2012). Almost all of these accounts agree that, "[an] explanation must enable us to see what sort of difference it would have made for the explanandum if the factors cited in the explanans had been different in various possible ways" (Woodward 2003, 11). Consequently, we can see why explanations are such a good source of understanding: they provide a large amount of the modal information about the space of possibilities involved in understanding a phenomenon.

Moreover, I suggest that the more modal information one grasps about the possible states of the target phenomenon, the better one understands the phenomenon.[10] The kind of possibility of interest to scientists will be different in different context (e.g. logical possibility vs. biological possibility), but I suggest that learning about how the phenomenon would or would not be

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[10] There are, of course, other ways to improve one's understanding as well.

different in various possible counterfactual situations always improves one's understanding. This highlights another important feature of understanding: unlike knowledge or explanation, understanding seems to clearly come in *degrees* (Kvanvig 2003; Elgin 2017).[11] For example, some people understand a subject matter better than others. This feature of understanding is important for two reasons. First, it suggests that there might be degrees of understanding that fall below the understanding provided by having a complete explanation (Lipton 2009; Rohwer and Rice 2013, 2016). In science, this allows for the improvement of understanding without requiring that scientists be able to provide an explanation.[12] The second important thing about understanding coming in degrees is that understanding of a phenomenon might be improved *beyond* the understanding provided by an explanation. One way this can happen is when scientists provide multiple explanations for the same phenomenon (Bokuich 2018; Longino 2013; Massimi 2018; Morrison 2015; Potochnik 2017). In other cases, models that fail to explain might deepen our understanding beyond what our current explanations can provide (Rohwer and Rice 2013, 2016). The general point is that the degree of understanding science has about a phenomenon neither starts nor stops with the understanding provided by a single explanation.

We can now turn to the question of whether or not understanding is factive and, if so, what about the grasped body of information needs to be true (or accurate) in order for us to genuinely understand? As we saw earlier, the serious issue here is that much of the understanding produced by science depends, in essential ways, on idealizations that are known to

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[11] While explanations might be better or worse, or perhaps can be deepened, whether or not an explanation has been provided is typically treated as a threshold concept.

[12] This idea runs contrary to recent accounts that have claimed that the *only* way to understand a phenomenon is to grasp a correct explanation of the phenomena (Trout 2002; Strevens 2013). See Lipton (2009) or Rice (2016) for reasons to doubt that explanation is the only way to provide understanding.

be false. One way to try and accommodate this observation is to restrict the false assumptions to the periphery of our understanding. For example, Kvanvig suggests:

> [S]uppose that the false beliefs concern matters that are peripheral rather than central to the subject matter…When the falsehoods are peripheral, we can ascribe understanding based on the rest of the information grasped that is true and contains no falsehoods…In this way, the factive character of understanding can be preserved without having to say that a person with false beliefs about a subject matter can have no understanding of it. (Kvanvig 2003, 201-202).

This is similar to Strevens's requirement that understanding be provided by a correct explanation that provides an accurate description of the difference-making causes of the phenomenon (Strevens 2008, 2013). This allows idealizations to distort features that are irrelevant or make no difference to the phenomenon of interest. The problem with this suggestion is that essential idealization of difference-makers is often absolutely central to the models and theories scientists use to understand various phenomena. As Elgin notes, in science, "elimination of idealizations is not a desideratum. Nor is consigning them to the periphery of a theory" (Elgin 2007, 38). Indeed, the literature on scientific modeling reveals myriad examples in which idealizations play ineliminable and central roles within scientists' attempts to explain and understand the phenomena we observe (Batterman 2002; Batterman and Rice 2014; Morrison 2015; Potochnik 2017; Rice 2017, 2018).

Another issue with Kvanvig's suggestion is that idealizations are rarely *believed* by the scientists that use them. This goes back to the earlier point that most accounts seem to conflate the idealized model itself with being an explanation or providing understanding on its own. If this is so, and idealizations are central to those models, then the idealizations will be central to our understanding. Moreover, when scientist make use of multiple conflicting idealized models to investigate the same phenomenon, this would result in our understanding including multiple conflicting claims about the phenomenon. However, I think it is a mistake to assume that all the assumptions of the idealized models used within science are automatically constituents of

science's understanding of a phenomenon. Instead, "It is only through the *use* of models, or indeed any other kind of object or representation, that scientists acquire understanding of the world" (de Regt, Leonelli and Eigner 2009, 12). As a result, I argue that the modal information required to understand a phenomenon is typically *strategically extracted* from the use of idealized models. This means that not every idealization used in the production of scientific understanding need be included in the understanding scientists have of a phenomenon—even if those idealizations were essential to producing that understanding.

Still, there is a sense in which our account of understanding ought to accommodate the idea that scientists might unknowingly believe some falsehoods or distortions without undermining the facticity of their understanding.[13] Indeed, the history of science clearly shows that unknowingly believing some falsehoods is common within scientific practice.

In light of this, my view is that understanding is factive because in order to genuinely understand a phenomenon *most* of what the agent (or community) believes about the phenomenon and the counterfactual dependencies and independencies that hold between features of real systems and that phenomenon must be true (Rice 2016, 2019). This does not mean that determining if an agent understands requires determining whether the percentage of true beliefs within their understanding meets some universally applicable threshold (e.g. eighty percent). For one thing, in different contexts, some pieces of information will be more important (or salient) to one's understanding and so the correctness of those beliefs will carry more weight in determining whether one's understanding meets this factive requirement. Other issues concern cases where one's beliefs are only approximately true or are inferred from other false beliefs. These issues

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[13] Indeed, if someone had an extensive set of justified true beliefs about the Roman Empire (and various related counterfactual situations), but also believed that Rome was currently on the northern border of Italy, we would not thereby claim that they failed to understand the subject matter at all—although their understanding might be improved by correcting this false belief.

suggest that the factive component of understanding will have to be somewhat context sensitive and allow for the possibility that one who understands might believe some (central) falsehoods about the phenomenon.

Nonetheless, I contend that the body of information that constitutes science's understanding will often be 'true enough' for us to maintain that genuine understanding requires meeting a factive requirement. For example, scientists' understanding of the movement of planets seems to clearly meet this factive requirement since—although it may contain some false beliefs—it is mostly constituted by true beliefs and those beliefs are particularly salient in the context of inquiry; e.g. where the earth is, how planets rotate, which bodies orbit which others, and the elliptical shape of the orbits. Moreover, scientists' understanding of this phenomenon also includes a plethora of correct information about how planetary motion would be different in a range of counterfactual situations; e.g. if the earth's orbit were altered or the earth's mass had been different. If scientists were systematically wrong about these salient facts or counterfactual situations, then they would fail to understand the phenomenon. Yet, given that most of their beliefs about planetary motion and how changes to the features of the system would change it are true, we ought to conclude that scientists do genuinely understand a great deal about planetary motion. This conception of understanding is still conspicuously factive since truth continues to play a key role in our judgments about whether or not we genuinely understand.

Here it is worth highlighting an important contrast between my view and the view defended by Elgin. Because Elgin's view requires exemplification, her view fails to accommodate cases in which drastic distortion of the salient features is used to further our understanding. The problem is that, as Elgin herself suggests, "Many scientific models such as equations and diagrams, are incapable of instantiating the properties they apparently impute to

their targets. If they cannot instantiate a range of properties, they cannot exemplify them." (Elgin 2017, 258). Elgin's response to this objection is that these models are often true enough for purposes of understanding "because the models are approximately true, or because they diverge from truth in irrelevant respects, or because the range of cases for which they are not true is a range of cases we do not care about" (Elgin 2017, 261). This is fairly close to the suggestion made by Strevens and others that idealized models can be used to produce understanding as long as their idealizations only distort irrelevant or negligible features. In contrast, I argue that idealized models that are used to produce understanding are often not approximately true and distort significant difference-making features that the researchers take to be relevant. Therefore, I argue that limiting the contributions scientific models make to understanding to the features they (approximately) exemplify or instantiate is too narrow. Features can be emphasized, deemphasized, and learned about via the use of scientific representations without having to accurately represent, exemplify, or approximate those features.

Another key difference with Elgin is that, while she takes the central role of idealization in science to require a nonfactive conception of understanding, I maintain that the central role of idealization *in the extraction of modal information* is compatible with a factive conception of the understanding produced by science. The key to recognizing this possibility is to separate the assumptions of idealized scientific representations from the modal information extracted from scientists' strategic use of those representations. I will provided some more detailed examples of how this can occur in the next section.

Let me now state my account of understanding more explicitly. Factive scientific understanding of a phenomenon is achieved when *an agent (or community) grasps some correct modal information about the counterfactual dependencies and independencies that hold between*

features of the system and the phenomenon and the agent (or community) grasps how that modal

information can be systematically incorporated into a larger body of information in which most

of what they believe about the phenomenon is true (Rice 2016). It is important to note that this

account leaves open the possibility that some (and perhaps central) propositions of the

representations that contribute to one's understanding might be false or inaccurate. Moreover, on

this account, the more accurate modal information that is grasped about how changes in the

features of the system would result in changes in the phenomenon, the better (or deeper) one's

understanding of that phenomenon.

4. Extracting Modal Information from Highly Idealized Models

Using the above account of factive understanding, in this section I use examples from scientific

practice to argue that factive understanding can be produced by (multiple conflicting) idealized

models that inaccurately represent most of the features of their target system(s)—including

features that are known to make a difference to the phenomenon of interest. This understanding

is constituted by modal information regarding how changes in the observable and unobservable

features of the system would result in changes in the phenomenon. This information is revealed

by investigating various possible states of the target system(s) that illustrate how the

phenomenon would have been different if various features of the system had been (perhaps

radically) different then they are in the actual case. The examples provided here also illustrate

how the assumptions of idealized models can be distinguished from the understanding extracted

by scientists' use of those models.

4.1. Example #1: The Exploration of Possibilities

One way that idealized models that distort difference-making features can produce understanding is by using the model to demonstrate how something is possible by modeling a hypothetical (but nonactual) system (Lipton 2009; Nozick 1981, 12; Weisberg 2013). That is, the model is used to extract information about how the phenomenon counterfactually depends (or fails to depend) on various features of the system by investigating a merely possible system that shows how changing the actual features of the system result in changes in the phenomenon of interest. As Lipton suggests, in these cases "the kind of understanding gained is modal, but here what is gained is knowledge of possibility" (Lipton 2009, 49). Indeed, since grasping modal information about the possible states of the system provides understanding, exploring nonactual possible systems can produce understanding without aiming to accurately represent the features of any real-world system.

An example of this kind of modeling is the use of the Hardy-Weinberg model in population genetics (Morrison 2015; Hartwell et al. 2000; Relethford 2012). This highly idealized model represents the change in the distribution of alleles in an infinite population of organisms that mate randomly and are not subject to migration or mutation (Relethford 2012; Stoneking 2017). This is a rather drastic distortion of the causes and processes that biologists know make a difference to actual evolutionary outcomes. No population is infinite and this assumption distorts the processes that result in drift (and selection) within real biological populations. Furthermore, all populations are subject to a plethora of other evolutionary influences such as selection, mutation, and migration, but each of these is distorted (or simply ignored) within the Hardy-Weinberg model. In addition, the Hardy-Weinberg model assumes that there is no intergenerational overlap. However, this is false of (almost) every real-world

population and is a difference-making feature for many evolutionary outcomes (Levy 2011; Morrison 2015; Stoneking 2017).

The model does, however, demonstrate that in such a hypothetical (i.e. possible) system, one generation of random mating will produce a distribution of genotypes that is solely a function of the allele frequencies in the previous generation. Moreover, the model shows that this distribution will be stable in future generations provided that the above assumptions are held constant. More specifically, the model tells us that if we have a pair of alleles, A_1 and A_2, at a particular locus and in the initial population the ratio of A_1 to A_2 is p to q, the distribution for all succeeding generations will be:

$$p^2A_1A_1 + 2pqA_1A_2 + q^2A_2A_2$$

regardless of the distribution of genotypes in the initial generation. By idealizing most of the influences on the population's evolution, the model allows one to calculate the genotype frequencies after a round of random mating simply by knowing the allele frequencies in the previous generation.

Despite its myriad distortions of difference-making features of actual biological populations: "The Hardy-Weinberg law enables us to understand fundamental features of heredity and variation…Hence, the claim that the law is false in some sense misses the point if our concern is understanding and conveying information" (Morrison 2009, 133). The key question is exactly how the model is able to produce this understanding of variation and heredity in actual biological populations.

One way the Hardy-Weinberg model produces understanding is showing *how it is possible* for variation to be maintained across generations within a Mendelian framework. This result is important because before demonstrating the stability of the distribution of genotypes,

Darwinians believing that blending inheritance would lead to decreased variation in each successive generation. This was problematic because natural selection requires variation. The Hardy-Weinberg model answers the question, "How is it possible for the genetic structure to be maintained over successive generations?" (Morrison 2009, 134). This insight provides correct information about a modal possibility that is relevant to understanding how actual biological systems evolve. What is more, these results concerning how the biological population would behave in a radically different possible system help scientists see how changing various observable and unobservable features of the real system would result in changes in the phenomenon. This modal information concerning how changes in these features result in changes in the phenomenon can then be incorporated into a larger body of information that constitutes the scientific communities' overall understanding of evolutionary phenomena. Since most of this information—as well as the modal information provided by investigating the Hardy-Weinberg model—is correct, we can see how the model contributes factive understanding of real biological phenomena despite its being pervasively idealized.

Rather than being an isolated case, the Hardy-Weinberg model is part of a large class of biological models that produce understanding by drastically distorting the evolutionary processes of real populations. Other examples include the Hawk-Dove model or the Prisoner's dilemma (Rohwer and Rice 2016). These models produce understanding not by accurately representing the features of actual systems, but by modeling systems that are merely (biologically) possible. Indeed: "Selectionists have devoted a great deal of effort to the construction of models that are aimed at demonstrating that some observed or suspected phenomena are possible, that is, that they are compatible with the established or confirmed biological hypotheses" (Beckner 1968, 165). The key in these cases is that models that represent possible (but non-actual) systems can

still provide correct modal information by showing how the phenomenon in question could have arisen (Lipton 2009, 51). By answering questions about the possibility space of the phenomenon, the model provides true modal information about the features of biological populations despite its drastic distortion of the difference-making features of all real biological populations. By incorporating this modal information into a larger body of information about how biological populations evolve, scientists come to (better) understand heredity and the transmission of variation.

> Elgin discusses the understanding produced by the HW-model somewhat differently:
>
> The Hardy-Weinberg model…exemplifies the pattern in the redistribution of the alleles in the absence of evolutionary pressures. Inasmuch as evolutionary pressures are always present, the model cannot, nor does it pretend to, account for allele distribution more generally. It is, however, very useful for some purposes. If population geneticists want to understand how significant an evolutionary factor such as migration is, they need a base rate. They need, that is, to know how alleles would redistribute in its absence (Elgin 2017, 263).[14]

However, it is a bit unclear how, on Elgin's view, exemplifying a pattern that fails to occur in any actual system is able to produce understanding. That is, the Hardy-Weinberg model fails to exemplify the salient features of any real-world biological population. Therefore, it is unclear how Elgin's view, based on exemplification of the features of real systems, is able to show how the Hardy-Weinberg model produces understanding. In contrast, I have argued that the Hardy-Weinberg model produces factive understanding of real biological phenomena because it enables biologists to grasp true model information about how the system would behave had various real features been (drastically) different in the ways represented by the model. In other words, the Hardy-Weinberg model produces understanding not because it exemplifies or accurately represents the features of real biological populations, but because it provides true information about how changing the features of real systems would change the dynamics of the population.

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[14] This is very close to de Regt and Gijsbers's (2017) idea that non-veridical models can promote understanding by being useful for moving science forward.

This understanding is produced by investigating a merely possible system in order to show how changing the features of real biological populations would result in changes in the phenomenon of interest.

4.2. Example #2: Multiple Conflicting Models and Overall Understanding

As we saw above, a major challenge for realist (or factivist) approaches to science comes from the use of multiple inconsistent models to understand the same phenomenon (Massimi 2018; Morrison 2011, 2015; Rice 2019). Across many sciences, multiple conflicting scientific representations are required to provide a complete understanding of a phenomenon (Green 2013). These models typically provide incompatible representations of the difference-making features of their target system(s). Thus, if we required models that are used to understand (or explain) to accurately represent difference makers, then the realist would be forced to either endorse incompatible claims about the features of the target system or deny that such cases can produce genuine understanding. Elgin's view based on exemplification also seems to face a challenge here. When models provide genuinely inconsistent representations of the salient features of their target systems, it is unclear how we can interpret the understanding these models provide in terms of exemplification of salient features. After all, the models each describe those features in contradictory and idealized ways. The way around these issues, I propose, is to see how each of the conflicting models can contribute to scientists' overall understanding of the phenomenon by providing accurate modal information without having to accurately represent or exemplify the features of their target system(s).

As an example, scientists make use of multiple inconsistent models to study the nucleus (Morrison 2011). In fact, there are over *thirty* different nuclear models, each of which provides

insight into some aspects of nuclear structure and dynamics. What is troubling for the realist is that the set of assumptions made by any one of these models is in conflict with fundamental claims made by the others. For example, "some models assume that nucleons move approximately independently in the nucleus … while others characterize the nucleons as strongly coupled due to their strong short range interactions" (Morrison 2011, 347). In other words, the models scientists use to study the nucleus routinely provide idealized representations that are inconsistent with one another regarding precisely those features that scientists take to be most salient. As Morrison explains, "nuclear spin, size, binding energy, fission and several other properties of stable nuclei are all accounted for using models that describe one and the same entity (the nucleus) in different and contradictory ways" (Morrison 2011, 349). The challenge, of course, is seeing how such a conflicting set of idealized models can yield (factive) understanding.

I suggest that the realist ought to reject the assumption that accurate representation (or exemplification) is essential to interpreting these idealized models as providing genuine factive understanding. Instead, I argue that we should interpret these various nuclear models as capturing different pieces of modal information about nuclear behaviors across different ranges of perturbations to the physical features of nuclear systems (Rice 2019). That is, these models produce understanding by modeling different ranges of possible systems that illustrate how changing (different) features of the actual system(s) would result in changes in the phenomena of interest. For example, the liquid-drop model captures one set of true modal information about nuclear phenomena by looking at a certain set of possible systems that change certain features of real systems, whereas the shell model might capture another set of true modal information about nuclear phenomena by looking at a different set of possible systems in which different real

features are altered, and so on for the other models. The general idea is that conflicting models can be used to extract different sets of modal information about the nucleus without having to interpret any one of the models as an accurate representation of the actual features of real nuclear systems. Indeed, while no single model is able to account for all the features of nuclear phenomena, these models have provided "an explanatory foundation for understanding certain processes" (Morrison 2011, 350). I argue that this is because multiple conflicting idealized models can be used to produce different sets of counterfactual dependence information about the target system despite the inaccuracy of the models used to extract that modal information. This counterfactual dependence information about how changes to the features of the system would change the phenomenon can then constitute a coherent (and consistent) body of information about the phenomenon even if the models used to explore those possibilities represent incompatible systems. Just because the representations of the liquid drop model and the shell model are incompatible does not entail that the counterfactual dependencies the liquid drop model reveals about real systems will conflict with the counterfactual dependencies revealed by the shell model. The modal information extracted from these multiple conflicting models can then be incorporated into physicists' overall body of information concerning nuclear phenomenon, which is constituted by mostly true beliefs about the nature of the nucleus and how changing the features of the nucleus would result in changes to various phenomena that are of interest to physicists. As a result, the use of multiple conflicting models can improve scientists' body of factive understanding even if none of the models provides an accurate representation of the difference-making features of real systems in which that phenomenon occurs.

Elgin addresses this case quite differently. She says:

> …if what one model highlights is that in some significant respects the nucleus behaves like a liquid drop, and another model highlights that in some other significant respects it behaves as though it has a shell structure, there is in principle no problem. There is no reason why the same thing should

not share some significant properties with liquid drops and other significant properties with rigid shells. (Elgin 2017, 270)

While this is somewhat helpful in moving us away from focusing on accurate representation relations, Elgin's proposal requires that the features these models enable us understand ought to be exemplified (i.e. instantiated) in some way. That is, what the models enable us to understand must be what each model has in common with the actual systems. This works fine when the salient features involved in the understanding provided by one model are sufficiently different and separable from the features involved in the understanding provide by another model. The issue is that in many instances—including the multiple conflicting models of the nucleus—this assumption cannot be made. As Morrison notes, cases in which different aspects of the phenomenon can be investigated by idealizing the system in different ways are importantly different from cases of genuinely inconsistent models like those in the nuclear modeling case. In this case, each of the models "makes very different assumptions about exactly the same thing" (Morrison 2011, 347). As a result, we cannot interpret these cases as merely exemplifying different aspects of the phenomena of interest. Instead, these models provide contradictory representations of the same features of the system in order to explore alternative possible states of the system. By seeing how exploring these various contradictory possibilities can produce understanding of the actual phenomenon via the extraction of modal information, we can see how scientists have developed a large body of factive understanding of nuclear phenomena despite the fact that the models used to produce that understanding fail to accurately represent or exemplify the salient features of real systems.

5. Understanding Realism

In light of the above discussion, I contend that the use of pervasively inaccurate representations in science can be made compatible with a version of realism that I call Understanding Realism. According to this view, the primary epistemic aim of science is factive understanding and this aim can be, and often has been, accomplished by the use of models (and theories) that inaccurately represent most of the features of their target system(s) (Potochnik 2017; Rice 2016, 2019). The key is noting that the understanding provided by scientists' use of idealized models ought to be separated from the representational accuracy of the models and theories used to produce that understanding. According to Understanding Realism, factive understanding of natural phenomena is provided by the correct modal information *extracted from* idealized models. Importantly, this means that the plethora of modal information included in scientists' understanding of various phenomena need not include the inconsistent assumptions included in the various (conflicting) idealized models used to study those phenomena. In short, the grasping of the modal information required to understand natural phenomena can be separated from the detailed assumptions involved in constructing the various idealized model systems used to extract that information.

Distinguishing the understanding provided by models from the assumptions of the models themselves allows us to maintain a factive conception of scientific understanding despite the central use of idealization in science. In contrast, Elgin argues against any kind of *veritism* that takes truth to be necessary for epistemic success, since "if we accept it, we cannot do justice to the epistemic achievements of science" (Elgin 2017, 9). Specifically, Elgin argues that "The more serious problem comes with the laws, models, and idealizations that are acknowledged not to be true but that are nonetheless critical to, indeed at least partially constitutive of, the understanding that science delivers" (Elgin 2017, 14). While I am sympathetic with many

aspects of Elgin's views, I disagree with the claim that the understanding produced by scientific inquiry must be *partially constituted* by (all of) the idealizations used in science. Although theories, models, and idealizations are certainly the tools with which scientists produce understanding of various phenomena, it does not directly follow that the assumptions involved in those tools must be included in the understanding *extracted from* scientists' uses of those tools. If this separation between the representations used by scientists and the understanding provided by scientific inquiry is possible, then recognizing the central role of (multiple conflicting) idealized models in science need not force us to adopt a nonfactive conception of scientific understanding. Indeed, the account defended above maintains the requirement that the modal information used to understand a phenomenon *must be constituted by mostly true beliefs about how changing the observable and unobservable features of the system would change the phenomenon* without requiring that the models used to produce that understanding be accurate representations of the relevant features of their target system(s).

In line with this account of understanding, I contend that realist approaches to science ought to focus their attention on science's ability to provide factive understanding of patterns of counterfactual dependence and independence rather than on the truth or accuracy of our best theories and models themselves. Despite their drastic distortion of the features of real systems, scientific models can provide a wide range of true modal information about the counterfactual relevance and irrelevance of various features of real systems to the occurrence of natural phenomena (Batterman and Rice 2014; Massimi 2018; Rice 2013, 2016, 2017). Moreover, by building multiple conflicting models that explore different possible states of the system, scientists can extract a plethora of modal information that can be used to better understand the phenomenon (perhaps in a variety of ways). As a result, realists can claim that science is able to

achieve the epistemic success of factive understanding despite the fact that scientific models are typically highly idealized and conflict with one another. In fact, the above account suggests that realists ought to encourage such a proliferation of conflicting models since they will typically provide access to a wider range of modal information and, therefore, will provide more overall understanding than any single model (or perspective).

Before moving forward, it is important to look at what this view has in common with other (more traditional) kinds of realism. Indeed, given that Understanding Realism denies one of the central tenets of realism—that our scientific models and theories are accurate descriptions of real world phenomena—it is worth taking a moment to consider why the above position ought to be considered a kind of realism. Moreover, given that I have argued that scientific models and theories are tools with which scientists extract modal information, one might think Understanding Realism has more in common with instrumentalism than realism.[15]

However, while I have argued that scientific models are tools that are used to extract information, a key difference between this view and instrumentalism concerns what scientists are able to use the models to produce. For the instrumentalist, the results are either accurate prediction or empirical adequacy regarding observable features of the phenomenon (van Fraassen 1980). In contrast, Understanding Realism argues that scientific models and theories can be used to produce the epistemic achievement of factive understanding which requires much more than mere accurate prediction of observable features. In particular, the model must enable us to see how various changes to the observable and unobservable features of the real system(s) would result in changes in the phenomenon of interest. The important point is that this factive epistemic achievement requires accurate information about counterfactual dependencies that

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[15] Thanks to an anonymous reviewer for pressing me to make the connection with realism and the distinction with instrumentalism clearer here.

hold between actual features of the system(s) and the predicted outcome—dependencies that will often hold between unobservables and the target phenomenon. This goes well beyond merely 'saving the phenomenon' or being accurate regarding only observable aspects of real systems. In short, while scientific models and theories are instruments, according to Understanding Realism, they are instruments for producing factive understanding which requires much more than empirical adequacy. Most importantly, the modal information involved in scientists' understanding of natural phenomena will (typically) be partially constituted by accurate information about unobservables and their dependence relations with the phenomenon of interest.

In addition, the view defended here has much in common with traditional forms of realism in terms of what it claims about the epistemic aims of science, the role of truth in those epistemic aims, and our being justified in believing that (our current) science has in fact achieved those epistemic aims. One way of thinking about the realism debate is as a debate about the aims of science and the epistemic achievements we are justified in believing scientific inquiry has accomplished (e.g. understanding of unobservables vs. empirical adequacy). The problem, I've argued, is that most realist accounts have assumed that the accomplishment of the realist's epistemic aims necessarily requires the development of true (or approximately true) theories or models. I think scientific practice makes clear that the epistemic achievements of science are accomplished via models and theories that drastically distort real systems. However, we can still be realists (of a sort) if we shift our consideration of these epistemic aims of science away from the theories and models themselves towards the modal information extracted from the use of those representations. By focusing on these epistemic achievements directly, we can see that, while it denies one of the central tenets of traditional accounts of realism, Understanding

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Realism still makes several realist claims about the aims and epistemic accomplishments of scientific practice.

First, my account argues that the aim of scientific inquiry is *factive* understanding. This means that science still aims at truth in an important way. Some philosophers have interpreted the reliance on essential idealizations as requiring the claim that science does not aim for truth or that science only aims for nonfactive epistemic achievements (Elgin 2017; Potochnik 2017). In contrast, I have argued that, despite the use of drastically distorted models and theories, science aims to uncover correct modal information about the counterfactual dependencies and independencies that obtain in the real world. In other words, the aim of facticity with respect to the epistemic achievements of science is consistent with the widespread use of grossly inaccurate scientific representations.

Second, the above account holds that the factive understanding science aims at includes lots of accurate information about unobservable entities and their relationships to observable phenomena. That is, it isn't just that these models and theories can be used to make accurate predictions of observable features, but that they can be used to extract true modal information about various observable and unobservable features of the system and how changes in those features would (or would not) change the results. This means that the epistemic aims of science often include providing accurate information about unobservables much like traditional accounts of realism.

Finally, Understanding Realism still maintains that we are justified in believing much of what science's factive understanding tells us about the operations of unobservable entities and their features even if we are not justified in believing the models and theories used to generate that understanding. That is, we are still justified in believing much of the information science has

provided about the nature of unobservable entities, processes, and features of real systems—that information is just contained in scientists' understanding of the phenomenon rather than being accurately reflected or mirrored by the representations used to discover that information.

In sum, Understanding Realism counts as a kind of realism because it: (1) makes a claim about the epistemic aims of science involving truth, (2) includes unobservable entities and their features within those truths that science aims at, and (3) makes a claim about science's epistemic successes in terms of achieving factive understanding of many natural phenomena. The mistake of traditional accounts of realism has been assuming that these factive epistemic aims must be achieved via (or within) true or accurate models and theories. By showing that these factive epistemic achievements can be accomplished by other means, we can preserve the realist's commitments regarding the aims and achievements of science without having to show that our models and theories accurately represent reality.

The most pressing issue for Understanding Realism is to show why we are justified in believing the counterfactual dependence (and independence) information we extract from scientific models given that we know those models are inaccurate representations. In response, I suggest that instead of relying on accurate representation or exemplification of difference-making features, realist approaches to science ought to appeal to the exploration of non-actual possibilities and the fact that many patterns of counterfactual dependence are *universal* across drastically different systems (Batterman and Rice 2014; Bokulich 2008, 2011; Morrison 2015; Rice 2017, 2018, 2019).

In many cases, such as the Hardy-Weinberg model, the justification for trusting the modal information extracted from the idealized model is that the model represents a highly idealized non-actual system that changes many of the features we know are present in real

systems. As a result, despite failing to exemplify or accurately represent the features of real biological populations, the Hardy-Weinberg model can show how changes to the actual features of the system would result in changes in the evolutionary dynamics of the population. This modal information is true and reveals important information about the dependence relations that hold within real systems. This is accomplished by constructing a model of a hypothetical scenario that changes the features of the real systems in particular ways and looking at the results when certain key features (e.g. migration, mutation, drift, etc.) are absent or altered.

In the second case, multiple conflicting models are used to extract modal information by having each of the models display different sets of counterfactual dependence relationships that are present in the real-world system. For example, the liquid drop model might display certain counterfactual dependencies present in real nuclear systems and the shell model might display some other counterfactual dependence relations between different features of the real system and the phenomenon of interest. Physicists' concept of a universality class becomes particular useful in such cases where the model(s) and the target system(s) are claimed to display similar patterns of counterfactual dependence despite the drastic distortions involved in each of the models. The term 'universality' is just an expression of the fact that many systems that are perhaps extremely heterogeneous in their physical features will nonetheless display similar patterns of behavior (Batterman 2002; Kadanoff 2013; Morrison 2015). The systems that display similar patterns of behavior despite differences in their physical features are said to be in the same *universality class* (Kadanoff 2013).[16] Physicists' interest in universality has typically focused on patterns that are stable across extremely diverse real systems; e.g. the universality of critical exponents across a wide range of fluids and magnets (Batterman 2002). However, I argue that scientists also use

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[16] As physicist Leo Kadanoff puts it, "Whenever two systems show an unexpected or deeply rooted identity of behavior they are said to be in the same universality class" (Kadanoff 2013, 178).

universality classes to find *model* systems that display similar patterns of counterfactual

dependence to those found in real systems despite rather drastic differences in their features

(Rice 2017, 2018).[17] Thomas Gisiger explains how this works in physics:

> Universality has been described as a physicist's dream come true. Indeed, what it tells us is that a system, whether it is a sample in a laboratory or a mathematical model, is very insensitive to details of its dynamics…From a theoretical point of view, to study a given physical system, one only has to consider the simplest mathematical model possibly conceivable in the same universality class. (Gisiger 2001, 173)

After reviewing how this works in physics, Gisiger then argues that when it comes to modeling

complex systems in biology, "One only has to choose a simple, or simplistic, model in the same

universality class as the system under study" (Gisiger 2001, 175).

When an idealized model system is within the same universality class as its target

system(s), the model will display similar patterns of counterfactual dependence and

independence despite the fact that the model may drastically distort the causes, mechanisms, or

other features responsible for the phenomenon in real-world systems. For example, physicists

have discovered that, despite drastic differences in their molecular details, a wide range of fluids

display the same phase transition behaviors near their critical points (Batterman 2002). What is

more, physicists have discovered that these same universal patterns are displayed by highly

idealized models that look nothing like the real fluids whose behavior they are used to

investigate (Batterman and Rice 2014). Despite these distortions, by delimiting the universality

class of systems—which includes the idealized model systems—that display these universal

patterns, physicists have discovered that these behaviors counterfactually depend on various

features of real systems; e.g. the order parameter of the system. Moreover, physicists have used

various mathematical modeling techniques such as the renormalization group to demonstrate that

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[17] I refer to a model system as the abstract system represented by a scientific model that includes all and only the features specified by the model (within a particular modeling context).

most of the other features of these systems could be changed (or perturbed) without altering the critical behaviors of the system. All of this is accomplished without constructing a model that accurately represents or exemplifies difference makers. By identifying universal patterns of behavior, scientists can link the modal information extracted from their investigations of idealized models with patterns of counterfactual dependence and independence present in real systems. The stability of certain relationships of counterfactual dependence and independence across scientific models and real (or possible) systems enables scientists to justifiably use idealized models that drastically distort difference-making features to understand the behaviors of their real-world target system(s) (Batterman and Rice 2014; Rice 2017, 2018).

In many cases—e.g. the multiple conflicting models case described above—similar patterns of counterfactual dependence will be displayed by systems with very different components, interactions, and processes. In these cases, scientists often construct pervasively distorted models that only include a few minimal features, but are amenable to the mathematical modeling techniques they have available. For example, in many cases "the large-scale structure is independent of a detailed description of the motion on the small scales. We can exploit this kind of 'universality' by designing the most convenient 'minimal model.'" (Goldenfeld and Kadnoff 1999, 87). The resulting idealized model can then be used to investigate how changes in various features of the system are counterfactually related to the phenomenon of interest. When the idealized model is in the same universality class as the system(s) of interest, scientists can justifiably use the idealized model to discover how changes to the features of the system would result in changes to the phenomenon of interest (Rice 2017, 2018).

I want to conclude this section by briefly mentioning two important implications of Understanding Realism that deserve to be explored in more detail than the space I have

remaining allows. First, it is important to note that the body of modal information that constitutes the scientific community's current understanding of various phenomena has been contributed to by multiple contradictory models and theories across time. Understanding Realism suggests that just as multiple conflicting modeling approaches can each contribute to the production of factive understanding by exploring different possible states of real systems, so too can conflicting idealized models and theories used at different points in the history of science.[18] That is, the above arguments concerning the use of multiple conflicting models to understand the same phenomenon might be used to show how past scientific representations that conflict with our current models and theories can contribute to our current understanding of natural phenomena.

Along similar lines, Understanding Realism suggests that one of the best ways to improve science's overall (degrees of) understanding is through increased diversity of the kinds of scientists (and non-scientists) and modeling approaches working to understand a phenomenon (Longino 1990, 2002, 2013; Potochnik 2017; Solomon 2001). By incorporating the modal information accessible by a more diverse range of scientific researchers and modeling approaches over time—whose background assumptions, models, theories, and methods might be in conflict—science will achieve a more complete understanding of natural phenomena than is possible within the limitations of any single perspective. Both of these ideas have important implications for the realism debate, but, given their complexity, a full treatment of them will have to be provided elsewhere.

6. Conclusion

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[18] The challenge here is to say precisely which pieces of modal information ought to be retained across radical changes to the models and theories adopted by the scientific community.

I have argued that the fact that our best scientific models and theories are pervasively inaccurate representations can be made compatible with a more nuanced form of scientific realism called Understanding Realism. According to this view, science aims at and often achieves factive understanding of natural phenomena by grasping true modal information. Moreover, the facticity of this kind of understanding can be separated from the accuracy of the models and theories used to produce it. Going forward, I suggest philosophers look more directly at the factive epistemic achievements of scientific communities rather than focusing exclusively on the accuracy of our current scientific models and theories. Often the best way to understand our world—and the ways our world could be—is by having a diverse community of researchers construct multiple conflicting models that each drastically distort the difference-making features of real systems.

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