# LEVERAGING DISTORTIONS

## Explanation, Idealization, and Universality in Science

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For Laura and Willa

## Contents

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# 1 Introduction

A fundamental rule of logic is that in order for an argument to provide good reasons for its conclusion, its premises must be true. This book is about how the practice of science repeatedly, pervasively, and deliberately violates this principle. However, I will argue throughout this book that rather than being a shortcoming of science, scientists are extremely adept at strategically using drastic distortions of the world in order to discover truths that would otherwise be inaccessible to us.[1] In other words, I will argue that one of the most important achievements of science is the discovery of numerous ways to *strategically leverage pervasively distorted representations* in order to discover the truths we are interested in.

Philosophers love truth. Indeed, truth enters at the ground floor of most philosophical accounts of knowledge, understanding, and explanation. Typically, this is via some sort of truth or accuracy requirement for each of these epistemic achievements. Relatedly, it is often claimed that scientific models and theories only provide genuine explanations and understanding when they are accurate with respect to the relevant features of the phenomenon of interest. Scientists, too, typically maintain that scientific methods are a reliable way to develop models and theories that are getting progressively more accurate concerning the nature of reality. As a result, among philosophers and scientists alike, it is typically assumed that the best route to the epistemic fruits of science (e.g., explanation and understanding) is via the construction of models and theories that *accurately describe the relevant parts of reality*. As Peter Godfrey-Smith describes this realist position, “One actual and reasonable aim of science is to give us accurate descriptions (and other representations) of what reality is like” (Godfrey-Smith 2003, 176). Science is certainly the greatest epistemic achievement ever produced by human beings. Without science, we would lack explanations and understanding of planetary motion, chemical reactions, phase transitions, evolution, human and animal minds, social changes, and countless other phenomena. If explaining and understanding these phenomena require true or accurate representation, then the science that produces them must (at least aim to) be true or accurate—at least with respect to the contextually salient, difference-making, or otherwise important aspects of natural phenomena.

Following this generally realist approach, most philosophical accounts of scientific explanation involve some sort of truth or accuracy requirement for the set of claims that do the explaining; that is, the statements appealed to in the explanation must be true (Craver 2007; Hempel 1965; Kaplan and Craver 2011; Salmon 1984; Strevens 2008; Woodward 2003). More specifically, given that most accounts of explanation are explicitly causal, most philosophers have claimed that a necessary condition for a scientific theory or model to be used to explain something is that it be true or accurate with respect to the explanatorily relevant causes of the explanandum. As Michael Strevens puts it, "No causal account . . . allows nonveridical models to explain" (Strevens 2008, 297). Mechanistic accounts of explanation also agree that "good explanations accurately describe the causal structure of the world" (Craver 2007, 61). While several causal accounts have emphasized the role of idealization in achieving the aims of science (Potochnik 2017; Strevens 2008; Weisberg 2007a, 2013), even those accounts that allow for liberal idealization maintain that scientific representations that are used to explain ought to accurately represent the relevant causes of interest (Potochnik 2017, 157).

In addition, most philosophical accounts of scientific understanding involve factive requirements for the body of information included in an agent's understanding (Grimm 2006; Khalifa 2017; Kvanvig 2003; Mizrahi 2012; Strevens 2013, 2017). That is, genuine understanding requires that at least most of the information grasped be true or accurate.[2] In fact, in some cases, these accuracy requirements for explanation and understanding are combined by views that claim that "scientific understanding is the state produced, and only produced, by grasping a true explanation" (Trout 2007, 585–586; see also Strevens 2008, 2013). According to these views, genuine understanding can be achieved only by grasping an explanation that is true.

In line with these accounts of explanation and understanding, most philosophical accounts of scientific modeling have required models that provide explanations or produce understanding to meet certain accurate representation requirements; for example, the model must accurately represent the difference-making, contextually salient, or otherwise relevant causes or mechanisms responsible for the phenomenon (Craver 2006; Kaplan and Craver 2011; Potochnik 2017; Strevens 2008; Weisberg 2007a, 2013; Woodward 2003). In general, the idea is that the accurate representation of the relevant causes of the phenomenon is what enables us to explain or understand why that phenomenon occurred.

Throughout this book, I will refer to this collection of views as *the standard approach* or *the standard view*. This standard approach claims that the epistemic aims of science are best achieved by constructing scientific representations that are accurate with respect to the relevant, focal, difference-making, or otherwise contextually salient causes of the phenomenon. Referring to this collection of views as the standard view is not meant to imply that there is a complete consensus in the field regarding these issues. Indeed, there are numerous authors (e.g., Batterman 2002b, 2010; Bokulich 2008, 2011, 2012; Elgin 2017; Lange 2013a, 2013b; Morrison 2009, 2015; Potochnik 2017; Walsh 2007, 2010) whose departures from this standard view have inspired many of the views I defend in this book.[3] Still, despite this dissent, the tenets of the standard view are common to the majority of the most influential accounts of explanation, idealization, and modeling in the philosophical literature: for example, the mechanistic and causal views defended by Craver (2006), Kaplan (2011), Potochnik (2017), Strevens (2008), Weisberg (2013), and Woodward (2003), among others. These influential views all adopt causal (or causal-mechanical) accounts of explanation, agree that there is a special set of causes that must be accurately represented in order to explain, and suggest that idealizations within models that explain should be restricted to causes that are not difference makers, are negligible, nonfocal, or otherwise not of interest.[4]

Scientists frequently discuss how highly idealized models aid in their explanations and understanding of various phenomena. For example, Bohr's collective model of the nucleus is useful "in explaining nuclear fission. It is also useful for understanding a large class of nuclear reactions" (Halliday, Resnick, and Walker 2011, 1185). Indeed, a brief look at any science textbook or journal reveals a wide range of cases in which science relies heavily on the use of models that are always abstract and idealized to some degree.[5] Several philosophers have suggested that we reserve the term "abstraction" for the omission of features or details from a representation of a target system or systems; that is, abstraction leaves things out (Godfrey Smith 2009; Jones 2005). Idealization, in contrast, is a process that directly introduces some degree of distortion of the features of the target systems; that is, idealizations attribute features that are (typically known to be) inaccurate. In practice, however, this distinction is not nearly so clean (or even possible), because the abstraction of certain features will almost always introduce distortions with respect to other features. For example, leaving out environmental features distorts how genetics contributes to development (Longino 2013). For this reason, among others, my focus throughout this book will be on the role of *distortion* in science, which is typically but not exclusively introduced by the use of idealization.

Relatedly, while my discussion will tend to focus on the use of models in science, I think most of the claims that I make regarding models can be easily extended to theories as well.[6] While I will not be defending any particular account of the relationship between models and theories, I am sympathetic to several accounts that would warrant this extended application of my conclusions. For example, if theories are just collections of models (Giere 1988, 2006), then my conclusions about highly idealized models will likewise apply to theories. Alternatively, according to Nancy Cartwright (1983) and Margaret Morrison (2015), models play a mediating role between the claims of a theory and the application of that theory to real cases. Similarly, Ronald Giere (2006) argues that theories are sets of principles that provide the basis for constructing more specific models. If these views are correct, then models and theories will often include similar assumptions, abstractions, and idealizations. Consequently, although there are various ways of conceiving of the relationship between models and theories, I think the arguments presented throughout this book can be applied to both types of scientific representation. The important point, for my purposes, is that science continuously presents us with a vast array of representations that are, both purposively and unintentionally, drastically distorted descriptions of their target systems.

The widespread and essential use of distortion in science raises a puzzling question that has been at the heart of the idealization and modeling literature over the last several decades: if the epistemic aims of science are best achieved by the accurate (or true) representation of reality, then how can drastic distortion contribute to science's epistemic aims? More specifically, as a result of philosophers' focus on accurate representation of relevant causes, the central question of this book is: how can highly idealized models *that directly distort difference-making and contextually salient causes* be used to provide explanations and understanding of natural phenomena. In many ways, these questions are just more specific versions of one of the oldest and most central questions raised by the discipline of philosophy (Appiah 2017): what is the relationship between the external mind-independent reality and our human representations of that reality? While much of the past philosophical discussion focused on how (or whether) our mental representations reflect or distort reality, the rapidly growing philosophical literature on scientific modeling and idealization asks similar questions regarding the representations used within scientific theorizing. In light of this, we require philosophical accounts of science that enable us to address the fundamental tension between the accurate representation requirements suggested for the epistemic successes of science and the widespread use of pervasively inaccurate representations in scientific practice. The representations used to accomplish the epistemic achievements of science have always been, and will continue to be, pervasive and drastic distortions of reality. We need a philosophy of science that can make sense of how this can be so.

To this end, the main goal of *Leveraging Distortions* is to provide an alternative philosophical approach to science that focuses on the positive and ineliminable contributions that the drastic distortion of causally and contextually relevant features makes to the epistemic achievements of science. That is, my alternative view will be built around the strategic leveraging of essential distortions *of relevant features* in order to discover explanations and understanding that would otherwise be inaccessible. While several other philosophers (e.g., McMullin 1985; Potochnik 2017; Strevens 2008; Weisberg 2007a, 2013; Wimsatt 2007) have emphasized the role of idealization in science, rather than focusing on eliminating, isolating, sidelining, or quarantining the role of idealization to the distortion of irrelevant or nonsalient features, my approach puts the positive epistemic contributions of pervasive misrepresentation of relevant features front and center.

As a result, I follow Angela Potochnik (2017) and Catherine Elgin (2017) in arguing that the epistemic aims of science can often be better achieved by rather drastic departures from the truth (i.e., idealizations are "felicitous falsehoods" [Elgin 2007, 39]).[7] While I agree with these authors that idealization plays a much more significant role than other philosophers have suggested, we take this recognition in quite different directions. For example, whereas Potochnik's central thesis is that science does not aim at truth and Elgin argues that scientific understanding must be nonfactive, I will argue that science still aims at factive (i.e., true) explanations and understanding—those epistemic aims are just achieved via scientific representations that drastically distort the relevant features of the phenomenon of interest.[8] Moreover, where Potochnik focuses on causal explanations and understanding, I offer noncausal accounts of explanation and understanding.

However, the most crucial difference to note at this point is that, while both Potochnik and Elgin allow for the distortion of some difference-making causes, their views still require that the salient, or contextually relevant, features of interest be accurately represented by scientific models that are used to explain or understand. For example, Potochnik's account of explanation requires that "posits central to representing a focal causal pattern in some phenomenon must accurately represent the causal factors contributing to this pattern" (Potochnik 2017, 157). This parallels the standard view's suggestion that idealized models explain only when they accurately describe the relevant causes and restrict their distortions to features that are nonfocal, negligible, or otherwise not of interest. Similarly, Elgin's view relies heavily on the idea that models that produce understanding must *exemplify* the salient features of interest: "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 use of highly idealized models to produce scientific understanding is then justified "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, again, is fairly close to the standard view's claim that idealized models can be used to explain and understand only when they accurately describe the relevant features of the system and their idealizations are restricted to the distortion of irrelevant, nonfocal, or negligible features. In contrast with both of these views, I will argue that the epistemic aims of science are often best achieved by scientific models that directly and drastically distort precisely those features that are known to make a difference, that are salient, and that are of interest to the current research program.

In sum, I will argue that the pervasive and drastic distortion of contextually salient difference-making features routinely makes epistemic contributions that are essential to the explanations and understanding produced by science. That is, I will argue that pervasive distortions of the relevant features of real systems are ineliminable from science's epistemic successes in the sense that, without those distortions, our best scientific models and theories would be unable to provide the explanations and understanding that scientists have given for many puzzling phenomena. However, despite their being produced via pervasively distorted representations, I will argue that these epistemic achievements of science can still be factive. By surveying case studies of idealized modeling from various sciences, we will see that scientific modelers are extremely adept at identifying diagnostic features of similar problems and then using idealizing assumptions to bring existing mathematical and theoretical modeling tools to bear on those problems. Indeed, the strategic use of the pervasive distortion of relevant features is one of the most widely employed and fruitful tools used in scientific theorizing.

What's more, scientific modelers typically justify the use of these idealized modeling techniques by appealing to features other than accurate representation. Specifically, scientific modelers often justify their introduction of these distortions by appealing to the assumptions required to use various modeling techniques and to the universality (i.e., stability) of various patterns across systems that are causally heterogeneous. Doing so enables scientific modelers to employ highly distorted models to explain and understand various patterns that occur across various real, possible, and model systems that are heterogeneous in most of their causes or mechanisms. This suggests that investigating the stability of universal patterns across causally heterogeneous systems is just as important to science as producing representations that accurately represent the causal relationships that led to particular events.

Along the way, I hope to break philosophers of science's heavy reliance on the accurate representation of relevant causes in order to understand the epistemic successes of science.[9] In many places, I will frame my views by critiquing the ways that other philosophers have addressed these questions, but I make no attempt to provide an exhaustive survey of all the available alternatives. Indeed, given the dominance of causal and mechanistic approaches, doing so would be nearly impossible! Consequently, I will discuss other approaches only to the extent that comparison with them helps to illuminate the ideas and arguments I aim to defend. My primary aim will be to argue that philosophers' narrow focus on the concepts of causation, accurate representation, and decomposition (into accurate and inaccurate parts) ought to be replaced by an alternative approach based on the concepts of modal information, holistic distortion, and universality. Such a shift will enable us to see that the pervasive distortion of causally and contextually relevant features is, and ought to be, an ineliminable and epistemically fruitful tool of scientific practice. However, before embarking on this path, it will be important to see in a bit more detail just why such an alternative account of science is needed.

## 1.1 Pervasive Distortion Is Central to Science

As I noted above, there is a puzzle at the heart of scientific practice: by introducing idealizing assumptions—which typically are known to be inaccurate—scientists frequently claim to have provided explanations and understanding of various natural phenomena. One of the main reasons for this widespread use of idealization is that the complexity of the world, in combination with our cognitive limitations, leads to many intertwined reasons to idealize (Potochnik 2017; Wimsatt 2007). For example, Michael Weisberg (2007a, 2013) distinguishes three kinds of idealization: Galilean, minimalist, and multiple models. According to Weisberg, what distinguishes these kinds of idealizations are the reasons that motivate their introduction and the "representational ideals" they ultimately aim at (Weisberg 2007a, 639). For instance, Galilean idealizations are introduced for reasons of computational tractability. However, given that tractability limitations will presumably be overcome at some point in the future, "Galilean idealization takes place with the expectation of future deidealization and more accurate representation" (Weisberg 2007a, 642). In other words, as Ernan McMullin originally argued, Galilean idealization takes place under the assumption that "models can be made more specific by eliminating simplifying assumptions and 'deidealization,' as it were" (McMullin 1985, 261).

Because these idealizations ought to be removed as science advances, if most idealizations in science were Galilean, then the widespread use of idealization wouldn't be so worrisome. That is, if most idealized representations were simply way stations on the way to more accurate models that did the real epistemic work, the use of idealizations in science could easily be justified by showing that they ultimately lead to accurate representations or true theories (McMullin 1985; Wimsatt 2007). However, throughout this book, I will argue that many of the idealizations in science—even those that aid in computational tractability—are not Galilean because they cannot be eliminated from the scientific representation in any principled way without also destroying the explanation or understanding achieved (Batterman 2002b, 2009; Batterman and Rice 2014; Morrison 2009, 2015; Rice 2013, 2017, 2018; Wayne 2011). In short, most of the idealizations used in science simply cannot in principle be eliminated in the way that accounts of Galilean idealization suggest. Often, this is because the idealizations are *deeply entrenched* in our best scientific models and theories, such that we have no way of knowing what a similar representation without those idealizing assumptions would look like. In short, not only is deidealization rare in practice, but also, in most instances, it is a philosopher's pipe dream.

More problematic for the realist's claim that science aims for accurate representation are what Weisberg calls minimalist idealizations. Minimalist idealizations aim at the construction of models that include only the core causal (or difference-making) factors that gave rise to the phenomenon of interest (Weisberg 2007a, 643–645). According to Weisberg, the reason for using minimalist idealization is tied to the goal of providing scientific explanations because—following the standard approach—most accounts suggest that explanations ought to accurately represent the difference-making causal factors and leave out (or idealize away) causal factors that are irrelevant (Craver 2007; Strevens 2008; Weisberg 2007a, 2013; Woodward 2003). Moreover, according to these minimalist accounts, these idealized models provide better explanations than more accurate models because accurately describing those features would misleadingly suggest that they are relevant to the phenomenon. Consequently, minimalist idealizations should not be removed as science progresses. Due to this permanence, minimalist idealization presents a bit more of a challenge to realists' claims that science aims at truth or accurate representation (Weisberg 2007a).

However, as we will see in later chapters, the problem of idealization is far more potent than accounts of minimalist idealization suggest because many of the explanations provided by science appeal to highly idealized models that *drastically distort relevant features as well* (Batterman and Rice 2014; Bokulich 2012; Potochnik 2017; Rice 2013, 2017, 2018). This is because in many cases, the only (or at least the best) explanation of a phenomenon requires idealizations that directly distort difference-making and contextually salient causes of the phenomenon (Batterman and Rice 2014; Potochnik 2017; Rice 2013, 2017, 2018). For example, optimality models in biology drastically distort the difference-making processes of natural selection that are of interest to adaptationists (Rice 2013, 2017, 2018). Models of fluids pervasively distort the causal processes that physicists know make a difference to phase transitions (Batterman and Rice 2014; Rice 2017). Modelers studying human behavior knowingly distort difference-making features of genes and the environment (Longino 2013). And the list goes on. Consequently, in addition to being ineliminable (i.e., non-Galilean), many of the idealizations used in scientific explanations cannot be restricted to the distortion of irrelevant features in the way that minimalist accounts of idealization suggest.

In addition, there are many essential idealizations in science that are used for purposes other than explanation. For instance, what Yasha Rohwer and I have elsewhere called "hypothetical pattern idealizations" are used in the construction of hypothetical scenarios that aim at the production of understanding (Rohwer and Rice 2013). These idealized models do not aim to explain the target phenomenon, but instead aim to investigate necessity or possibility claims. As a quick example, the Hawk-Dove game is a highly idealized game-theoretic model that investigates the possibility of individual-level selection producing restraint in combat. The model describes a population that is infinitely large, randomly pairs players, involves asexual reproduction, allows only symmetric interactions, and stipulates that all interactions involve exactly two players, that the payoffs for players are constant across iterations of the game, and that there is perfect correlation between winning the game and fitness (Maynard Smith 1982). Although biologists are well aware that such a system is impossible and drastically distorts how natural selection actually produced the phenomenon, the Hawk-Dove game enables us to understand that restraint in combat could *possibly* be the product of individual-level selection. However, as with many of the models used to explain, these hypothetical models make these epistemic contributions without accurately representing the difference-making or contextually salient causes of any real-world target systems.

What's more, while philosophical discussions of idealization have focused on the most egregious false assumptions (e.g., infinite populations, infinite numbers of particles, or perfectly rational agents), science is also filled with many more *garden-variety idealizations*: subtle distortions that are so common that, taken together, they add up to rather drastic departures from the truth (Cartwright 1983). This includes the use of discrete variables for continuous features (e.g., Bursten 2018a) or the use of continuous variables for discrete features. It also includes the smoothing of curves and the simplification of equations in order to make their solutions easier to calculate (Elgin 2017). As I mentioned above, also important here are the distortions of various features introduced by the abstraction of other features (Cartwright 1983; Walsh, Ariew, and Matthen 2002). Philosophers tend to ignore these kinds of distortion because they often seem easy to correct as science progresses. However, even when this is possible, it is rarely done in actual practice. Furthermore, in many cases, it in fact cannot be done without dismantling the scientific model or theory in question.

As a result, most of the explanations and understanding produced by science derive from models and theories in which myriad subtle distortions are maintained throughout repeated applications, right alongside more drastic idealizing assumptions. Consequently, when they are considered collectively, the various motivations and types of idealization used in scientific theorizing typically result in scientific representations that *pervasively distort most of the features of their target systems*—including those that are of interest and make a difference to the phenomenon. Although most of the cases that I will focus on in this book involve more egregious idealizing assumptions that cannot be removed in principle, it is important to remember that even these subtler distortions are widespread and rarely removed in practice.

To make matters even worse, in addition to pervasive idealizations that are introduced into particular scientific models (and theories), very often in science we find multiple conflicting idealized models being used to study the same phenomenon (Chakravartty 2010; Massimi 2018; Mitchell 2009; Morrison 2011; Odenbaugh 2005; Parker 2006; Rice 2019b; Sklar 1993; Weisberg 2007a, 2013; Wilson 2017; Wimsatt 2007). That is, across many scientific fields—including biology, physics, nanoscience, climate science, and economics—multiple idealized models are often used to investigate the same phenomenon, despite those models often including inconsistent theoretical assumptions about (or representations of) that phenomenon. We can see this clearly in Weisberg's characterization of "multiple models idealization" as "the practice of building multiple related but incompatible models, each of which makes distinct claims about the nature and causal structure giving rise to a phenomenon" (Weisberg 2007a, 645). The challenge is to show how such a situation can result in an improved overall understanding of the target phenomenon by integrating the insights provided by multiple inconsistent models. Furthermore, given that most philosophical accounts have relied on accurate representation of relevant causes, it is unclear how multiple conflicting (and known to be false) representations of the relevant features of a system could produce genuine explanations and understanding. I will refer to this challenge as *the problem of inconsistent models* (Chakravartty 2010; Massimi 2018; Morrison 2011, 2015; Rice 2019b).

There are certainly several other kinds of idealization in science besides those that I've mentioned here; this list is nowhere near exhaustive! The main point that I want to make here—and will argue for extensively throughout this book—is that essential and ineliminable idealization of relevant and irrelevant features is widespread in science. This raises a serious challenge to the standard philosophical approach to science because *we know that our best scientific theories and models are representations that pervasively distort both relevant and irrelevant features because we deliberately made them that way.* In sum, the challenge is to clarify how the widespread use of pervasive distortion can make essential and positive contributions to scientific explanations and understanding.

## 1.2 Responding to Pervasive Distortion

Within the philosophy of science, there have been two basic responses to science's widespread use of idealized models and theories to explain and understand. The first is to argue that the epistemic results of science depend only on the true (or accurate) parts of our scientific models and theories. That is, many accounts argue that the "premises" of scientific inferences are true (or accurate) with respect to the relevant, difference-making, or otherwise contextually salient features that scientists are interested in (e.g., Craver 2006, 2007; Elgin and Sober 2002; Hempel 1965; Kaplan and Craver 2011; Kitcher 1981; Pincock 2011; Potochnik 2007, 2009b, 2017; Strevens 2004, 2008; Weisberg 2007a, 2013). There are, of course, numerous differences among these views. However, each attempts to show that we are justified in accepting the knowledge, understanding, or explanations provided by science because the inferences used depend on models and theories that accurately describe the relevant, difference-making, or contextually salient features of real-world systems. Indeed, as I will argue in more detail in chapter 2, this decompositional strategy is widespread across a range of philosophical debates about explanation, idealization, modeling, and realism

(Rice 2017). The decompositional strategy tries to preserve the factive epistemic achievements of science by decomposing scientific theories and models into their accurate and inaccurate parts (or assumptions) and showing that the accurate parts are responsible for science's epistemic successes.

The other main response has been to argue that because the inferences of science essentially depend on models and theories that are known to be inaccurate, the epistemic results of those inferences must be nonfactive. That is, because some of the essential "premises" of the inferences are false, the conclusions of those inferences (i.e., the epistemic outputs of science) cannot aim at truth (Elgin 2007, 2017; Potochnik 2017).[10] This kind of response is also advocated by various nonrealists such as van Fraassen (1980) and Stanford (2003). In short, this response argues that we are somehow mistaken about the epistemic successes of science. Science does not in fact achieve factive explanations or understanding of natural phenomena; all that can be hoped for is empirical adequacy or nonfactive understanding.

Throughout this book, I will argue against both of these approaches and propose an alternative. According to my view, the representations used by scientists to explain and understand our world drastically and deliberately distort the relevant features of their target systems—including precisely those features that scientists are interested in and that are known to make a difference to the phenomenon of interest. In short, the "premises" of scientific inferences are known to be inaccurate even with respect to the relevant, difference-making, or otherwise contextually salient features of interest. As I suggested above, scientists often use idealizations in positive and ineliminable ways that pervasively misrepresent the model's target systems, including the relevant (e.g., difference-making or contextually salient) features of the target phenomenon. Moreover, scientists *should* be doing this. Philosophical views that suggest that such uses of idealization cannot contribute in positive ways to the epistemic achievements of science not only inaccurately describe the practice of science, but also harmfully suggest that scientists should not be using many of the most epistemically valuable tools in their arsenal. Often, it is only by pervasively distorting the relevant features of reality that scientists can discover the explanations and understanding we seek.

Despite this pervasive distortion, in contrast with the second approach, I will also argue that the epistemic outputs of science—in particular the explanations and understanding produced by science—are nonetheless factive. That is, I will argue that the "conclusions" that science extracts from its use of highly idealized (and abstract) models are true. The challenge, of course, is to show exactly how science is able to accomplish this seemingly magical feat, given that it violates one of the most basic rules of logical inference. The only way to do this, I suggest, is by looking in detail at the various (typically mathematical) modeling techniques used in scientific practice and the ways that scientists strategically leverage those distorted representations in order to extract the knowledge, understanding, and explanations we desire. Time and time again, scientists demonstrate that they are extremely adept at using drastic distortions of reality to further their (and our) epistemic aims.[11] As a result, even if one could construct a version of science that could proceed without the use of essential and pervasive distortion of relevant features, the history of scientific practice suggests that such a science would be *far less epistemically successful.*

My goal in this book is to develop new philosophical accounts of explanation, idealization, modeling, and understanding that enable us to make sense of how this could be so. Unfortunately, because essential idealization of relevant features fails to sit well with standard philosophical approaches to science, the centrality of these distortions to scientific practice often goes unmentioned in discussions about the methods of science. I have found that this is often also true in discussions among scientists themselves—at least in discussions of how to teach science to students, or how to promote a general public perception of how science works. In both cases, the essential and pervasive role of distortion of relevant features is largely sidelined in favor of characterizing science as a slow march toward more and more accurate representations of the relevant features of the natural world. Unfortunately, the willingness to promote this misleading description of how science works has led to widespread misunderstanding of how science has achieved the epistemic successes it has and how it might be made even more epistemically successful going forward.

Therefore, my goals in this book are both descriptive and normative. If it is to be useful to practicing scientists, the philosophy of science must go beyond merely describing science, and offer ways of improving scientific practice by illustrating how science works when it works well, as well as showing how to avoid erroneous inferences or methods. However, if the normative guidance offered by philosophers is too far divorced from the actual practice of science, then the lessons will be of little use. As a result, our normative philosophical accounts of science need to be closely tied to actual scientific practice.

I will argue that the standard responses to the challenges raised by idealizations are too descriptively inaccurate to offer much in terms of normative guidance to practicing scientists. Only if philosophers develop pictures of science that more accurately reflect the actual practices, methods, and justifications used by scientists will their normative prescriptions be of genuine use to the practice of science. My intended audience, therefore, is both philosophers and scientists (as well as students in these fields). I hope to get philosophers of science to update their views concerning scientific explanation, understanding, idealization, modeling, and realism in ways that scientists will find useful. I also hope that in doing so, scientists might find the ideas and arguments presented in this book genuinely helpful to their practice and to the teaching of that practice to others. In order to accomplish these goals, throughout this book I deliberately adopt a case-based, bottom-up methodology that begins with the detailed analysis of numerous case studies from scientific practice, from which I will construct my philosophical accounts of explanation, idealization, modeling, and understanding.

## 1.3 Plan of the Book

After grouping several prominent accounts of explanation, idealization, and modeling under the standard approach in chapter 2, I will begin by arguing that—contrary to most accounts of explanation—many explanations in science are *noncausal*. I do this in chapter 3 by providing an in-depth analysis of three types of noncausal explanations from across the sciences: optimization explanations, statistical explanations, and minimal model explanations. Drawing on features extracted from these examples, I present in chapter 4 an alternative view of explanation that focuses on providing information about both counterfactual dependence *and* counterfactual independence. The main advantage of this counterfactual approach is that it can capture the wide variety of noncausal explanations found across the sciences and show what they have in common with the numerous causal explanations provided in science. In addition, the account provides a direct connection between the discovery of explanations and the production of understanding. Finally, I will argue that the counterfactual approach provides a framework that is better able to accommodate the positive contributions made by essential and ineliminable idealizations to many scientific explanations.

After arguing for this counterfactual account of explanation, I move to show how essential idealizations routinely enable scientific modelers to produce explanations (and understanding) without accurately representing the relevant features of their target systems. Instead of attempting to decompose scientific representations into their accurate and inaccurate parts, I argue in chapter 5 for an alternative, *holistic distortion view* of idealized models. According to this view, the use of idealization is so pervasive that philosophical accounts of science ought to characterize scientific models as pervasive (rather than partial) distortions of their target systems. This isn't to say that models always distort every single feature of their target systems. Rather, according to the holistic distortion view, the distortions introduced by widespread idealization (and abstraction) in science are typically so pervasive that we are unable to identify which features of the target systems are being accurately represented and which are distorted. As a result, we need philosophical accounts of how science can be epistemically justified that do not require scientists to know how to decompose idealized models (or theories) into their accurate and inaccurate parts. The holistic distortion view contributes to this project by changing the way that we conceive of the representations provided by idealized models and how scientists' appeals to those representations ought to be justified. In particular, the holistic distortion view focuses our attention on the specific ways in which pervasively distorted models are leveraged by scientists to discover explanations and understanding that would otherwise be inaccessible.

In chapter 6 I develop this holistic distortion view further by showing how physicists' concept of a universality class can clarify how holistically distorted models can be justifiably used in the construction of scientific explanations and understanding. A *universality class* is a group of systems that display some universal (i.e., stable) behaviors despite (sometimes drastic) differences in their physical features (Batterman 2002b, 2009, 2010; Morrison 2015, 2018a). As the mathematician Terence Tao explains, "Over the decades, many such universal [patterns] have been found to govern the behavior of wide classes of complex systems, regardless of the components of a system or how they interact with each other" (Tao 2012, 25). By being in the same universality class as their target systems, idealized models—which are conveniently amenable to the various modeling techniques that scientists have on hand—can be justifiably used to discover explanations and understanding of real-world phenomena without having to accurately represented the causes or mechanisms responsible for those phenomena. What's more, by looking at a variety of examples from scientific modeling, I argue that this account better aligns with the justifications provided by scientists themselves for using highly idealized models to explain complex phenomena.

Furthermore, in chapter 7 I argue that universality classes also help us understand some of the ways that scientific modelers can overcome various challenges that arise in cases of *multiscale modeling* (e.g., the problem of inconsistent models and the tyranny of scales). Scientific modelers are often interested in phenomena whose relevant features span an incredibly wide range of spatial and temporal scales. The problem is that most scientific modeling tools have been developed to capture features at only one (or a few) scales of a system (Batterman 2013; Green and Batterman 2017). The concept of universality shows how multiscale modelers are able to overcome some of these challenges by investigating the scale-dependent, scale-invariant, and interscale relationships that are required to model complex phenomena with multiple conflicting models. Moreover, this investigation into various multiscale modeling techniques has important implications for philosophical debates concerning modeling, reduction, and emergence.

In addition to providing explanations, another primary epistemic aim of science is the production of human understanding (de Regt 2017; Elgin 2017; Khalifa 2017; Potochnik 2017). In chapter 8 I first argue that holistically distorted models can produce factive scientific understanding via routes other than explanation. I then use these cases to develop a factive account of scientific understanding that is compatible with science's widespread use of holistically distorted models. After we have seen the various ways that holistically distorted models can positively contribute to the epistemic achievements of science, we can begin to make the case for adopting a more nuanced form of scientific realism. This form of realism must acknowledge that our best scientific theories and models are pervasively inaccurate representations. However, according to the view that I will call *understanding realism*, these inaccurate scientific representations can still be used to produce a factive corpus of understanding of natural phenomena. I argue that this can be accomplished by moving our focus away from the accuracy of scientific models and theories themselves, and instead evaluating the factivity of the epistemic achievements produced by scientists' strategic leveraging of those distorted representations. Furthermore, my account shows how past models and theories can contribute to our current understanding of phenomena and how the epistemic aims of science are directly improved by increasing the diversity of researchers, methods, and modeling approaches in science.

In combination, these accounts of explanation, idealization, modeling, and understanding will allow us to better characterize the wide variety of ways that scientists leverage holistic distortions in order to better explain and understand our world. Putting these ideas together into an overall picture of scientific theorizing, in chapter 9 I first show how the ideas and arguments from earlier chapters provide answers to several important questions regarding scientific explanation that are largely ignored by traditional accounts (Potochnik 2018). In addition, I argue that these views clarify the ways that holistically distorted models provide better explanations and improve our overall understanding when compared to less distorted scientific representations. Finally, these views focus our attention on the essential role played by universal patterns in science, rather than on uncovering the causes of the phenomenon.

In summary, the central arguments of the book make the case for replacing each of the components of the standard approach with the following components of my leveraging holistic distortions approach:

| | Replace: Standard approach | With: Leveraging distortions approach |
|---|---|---|
| Chapters 3 and 4 | Causal explanation | Counterfactual explanation |
| Chapter 5 | Decomposition into accurate/inaccurate parts | Holistic distortion |
| Chapters 6 and 7 | Accurate representation | Universality classes |
| Chapter 8 | Realism about models and theories | Realism about understanding |

More specifically, I will argue that a counterfactual account of explanation ought to *subsume* causal approaches to explanation. In contrast, my holistic distortion view is meant to *replace* accounts that focus on accurate representation of relevant features. Thus some parts of the standard view can be subsumed, but others will have to be replaced. Doing so will enable us to develop philosophical accounts of science that explicitly recognize the essential and ineliminable use of pervasive distortion of relevant features *as a virtue rather than an obstacle* to the epistemic accomplishments of science.

Science is the greatest epistemic tool we have, but we need better accounts of how it does and should produce explanations and understanding via idealized models and theories. However, in order to provide alternative answers to these questions, we need to rethink many of our foundational philosophical assumptions and focus our attention on the variety of ways that holistically distorted models are strategically leveraged by scientists to explain and understand our world.

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