Introduction

TOWARD A SCIENTIFIC METAPHYSICS BASED ON BIOLOGICAL PRACTICE

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DESPITE THE DAUNTING COMPLEXITY of biological systems and frequent failures, scientists have made significant advances in their ability to investigate, explain, predict, and manipulate those systems. A central task for philosophy of science is to understand what makes biological science successful in these endeavors. More and more, philosophers are realizing that this cannot be done by focusing solely on scientific theories. Instead, we must understand science as a rich system of *practices,* of which theorizing is only one kind. In turn, the fact that science is effective at learning about the biological world suggests that studying those practices might yield lessons about general features of the world that they successfully investigate (for examples, see Kaiser 2015; Kendig 2015; Meincke and Dupré 2020). In other words, successful scientific practice might inform *metaphysical* discussions.

The purpose of this volume is to explore and elaborate on these ideas—to investigate issues at the intersection between biology, practice-focused philosophy of science, and metaphysics. That is, it explores how a study of biological practice might contribute to a development of *scientific metaphysics.* As we discuss, definitions of metaphysics generally and of scientific metaphysics specifically are a matter of constant debate, and we do not aim to settle the matter here. In this volume, we want to distinguish *scientific metaphysics* from *metaphysics of science.* Metaphysics of science aims to characterize the entities, structures, and relationships that are at the core of or are assumed by a scientific theory or paradigm. Metaphysics of science is a modest project about the structure of the world as it is conceptualized and engaged with by scientists. By contrast, scientific metaphysics aims to make claims about entities, structures, and relationships of reality that go beyond a system of conceptualization and practice—claims about what the world is like, not just what scientists take the world to be like. The scientific metaphysics aimed for in this volume is an ambitious one. As we discuss later, the aim of this volume is to extend an analysis of scientific metaphysics beyond the scope of traditional accounts that primarily focus on theory and prioritize features like fundamentality, simplicity, and unity. It is a contention of the authors in this volume that any scientific metaphysics that pays insufficient attention to biological practice is at risk of misinterpreting the metaphysical significance of the science.

The views expressed in this volume about scientific metaphysics are diverse, but an overarching conclusion that emerges is that a metaphysics of the biological world informed by scientific practice is possible, potentially fruitful, and intrinsically interesting in its own right. For some contributing authors, this is a controversial goal. Because the claims of this volume depend importantly on the epistemic practices of scientists, there is a serious question as to whether and how we are ever justified in extending metaphysical claims beyond a paradigm. Our invocation of the Kuhnian concept of paradigm is meant to signal that scientific knowledge is often an expression of scientific traditions—defining features of scientific communities whose activities and thoughts are informed by shared conceptual frameworks, core questions, practical applications, techniques, instruments, and background beliefs (Kuhn 1962). Bausman's chapter represents the most explicit discussion of this problem, but many of the chapters touch on this issue. Other contributing authors are more comfortable with the project of scientific metaphysics. For example, chapters 6 and 9 provide metaphysical accounts that tentatively go beyond any particular paradigm.

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In this introduction, we situate the volume against related and contrasting subjects and approaches, discuss foundational issues surrounding its themes, and summarize the individual chapters.

1. BACKGROUND: BIOLOGICAL PRACTICE AND SCIENTIFIC METAPHYSICS

1.1 The "Turn" to Practice in Philosophy of Science

Philosophy of science in recent years has become increasingly interested in scientific practice. This shift in focus is sometimes called the *practice turn,* drawing a parallel with the linguistic turn in philosophy in the early twentieth century. To call an intellectual development a "turn" is a rhetorical device that endows it with the gravitas of revolution, with a well-defined and radically different "before" and "after." Whether or not this is strictly true of the turn to practice in science studies (Soler et al. 2014), it is useful as a label for a mode of inquiry historians and philosophers of science increasingly adopt in their analyses of science and scientific progress. Just as scientists often adopt different strategies, perspectives, and methods to advance their understanding of the world, philosophers and historians of science can "turn" to the study of practice to gain a more accurate and comprehensive view of how science works.

A recent concern among historians and philosophers of science is that scholarly communities have spent too much time in a theory-focused mode and not enough in a practice-focused mode (Chang 2014). What exactly does it mean to do philosophy of science with a focus on practice? The introduction to the volume by Soler, Zwart, Lynch, and Israel-Jost (2014) provides an excellent overview of this movement and its history. It is best to understand the practice turn as a reaction to several perceived problems with how philosophy of science (and science studies more generally, including the history and social studies of science) has tended to be done in the past. In the early analytical tradition, philosophical treatments of science focused on scientific theories from a narrow range of inquiries, particularly physics, thought to describe the "fundamental" features of the world. On this view, the relationship between theories, predictions, observations, and evidence is reconstructed using abstract sets of propositions related to each other by universal rules of logic and probability theory (Hempel 1945; Hempel and Oppenheim 1948). The job of the philosopher of science is to rationally reconstruct and critically evaluate this logic of science (Reichenbach 1938). Following World War II and the emergence of the Cold War, there emerged from this tradition a general, overarching attitude to what science is and what aspects of it are amenable to philosophical study based on the implicit assumption that scientists (qua scientists) are individual, ideally rational agents whose sole aim is attaining truth (Reisch 2005). Epistemology is not interested in the actual psychological thought processes or the external sociological contexts of people doing science (called the context of discovery by Reichenbach), but only in reconstructing the most logical way to arrive at a result and how to present it to other scientists (the context of justification) (Reichenbach 1938).

It is this inherited attitude to science and its relation to philosophy to which the practice turn is a reaction. While many valuable insights came from this traditional approach to philosophy of science, it also led to many important facets of science being overlooked. For example, the approach's emphasis on universal laws of nature makes it hard to accommodate almost all areas of inquiry beyond physical mechanics (Mitchell 2003; Wimsatt 2007; Currie 2018). Moreover, as many philosophers, sociologists, and historians of science have argued, this focus leaves unaddressed many aspects of scientific inquiry that are crucial to scientific progress (Pickering 1992; Nersessian 2012; Leonelli 2016). Theoretical and conceptual success is intricately intertwined with epistemic activities including intervening, classifying, data gathering and organizing, modeling, and doing statistics. Scientific success is often achieved through an iterative process whereby new conceptual and technical developments help build upon and correct previous understandings and methods of interacting with the world (Chang 2004).

In short, practice-focused philosophers typically view science as a richly interconnected system of activities, skills, strategies, and background knowledge by means of which scientists investigate their domains for a variety of purposes. In particular, they avoid viewing science purely in terms of its theories. That isn't to say that theories are not important to science—they certainly are, though not always as much as supposed. Rather, it is dubious whether an adequate understanding of scientific theories can be had when studied in isolation from the investigative context in which they arise. This context shapes the structure a theory eventually takes. And when theories are important, they are important insofar as they affect how science is *done*—what questions are asked and pursued, what experiments are performed, how data are interpreted and evaluated, and so on. This contrasts with a theory-focused approach that grants those practical aspects a peripheral role, in which practice is just the means by which theories are developed and evaluated. A practice-focused approach takes the opposite view: theories get their significance from the wider system of practices in which they are embedded. Theories are just one of the tools in the scientists' toolbox, and just like the others, what matters is how they are used.

Along with contextualization of theory and focus on activity, practice-focused philosophers are typically interested in the complex realities of science rather than the abstractions and idealizations that were typical of traditional approaches to studying science. Most famously, Kuhn (1962) criticized the traditional view of scientific theory change on the grounds that it didn't fit with how scientific revolutions actually happen in history. Mistakes like these have been made, it is said, because of philosophy's failure to pay proper attention to how science actually works. Disabusing us of the idea that science is centered on testing and refuting hypotheses, Kuhn's portrayal of "normal science" drew attention to another aspect of theoretical work; namely, the articulation and extension of the theory's central hypotheses and exemplars. Since then, focus has also been drawn to the role of experimental work (Hacking 1983). A more drastic shift has been away from the traditional view of scientists as isolated, ideal agents and toward viewing them as encultured communities of imperfect human organisms with rich inner and outer lives and working with finite material and cognitive resources. Philosophers of scientific practice are often interested in how science succeeds within these constraints rather than imagining how it would or should be without them (Wimsatt 2007; 2023). In particular, philosophers of scientific practice often emphasize the idea that science is and has always been a purposeful activity, performed against a background of goals and values. This aspect overlaps strongly with feminist philosophy of science, which critically investigates those goals and values and the scientific ideas they support (see later).

Because of this interest in science as a complex system of activities, practice-focused philosophers often incorporate scientific methods into their research to understand that complex system. Practice-focused philosophy therefore overlaps strongly with *empirical philosophy of science,* which incorporates tools such as ethnographic studies of scientific communities (Nersessian 2012; Leonelli 2016; Kaiser and Trappes 2023), psychological experiment (Griffiths et al. 2009; Lombrozo 2010; Riesch 2015; Machery et al. 2017), or digital analysis of scientific literature (Lean et al. 2021; Overton 2013; Pence and Ramsey 2018; Mizrahi 2020). The hope with these methods is that philosophical preconceptions about science can be refined or overturned with observation, thereby enriching the picture of science on which our philosophy is based.

In summary, we take philosophy of scientific practice broadly to study science *in practice* instead of science *in theory*—rather than as an idealized phenomenon abstracted from its complex context. We will see various examples of how attention to practice shifts and expands philosophical discussions about science in the rest of this introduction and throughout the volume.

1.2 Scientific Metaphysics

The overarching aim of this collection is to further the cause of enriching the philosophy of science through the study of scientific practice by addressing a particular and largely overlooked aspect. Specifically, it explores how taking a practice-focused view of science can contribute to questions in metaphysics.

Metaphysics as a subject is notoriously hard to define (Sullivan and Van Inwagen 2020), but it is typically said to concern the nature of reality in some general, ultimate, or fundamental sense. Examples of subjects usually classed as metaphysical include existence, space, time, causality, identity, possibility and necessity, parthood, free will and determinism, natural kinds, and the place of mind or consciousness in nature. These subjects might be seen to concern what some consider the general categories of being and how they relate to each other. It is a common view among metaphysicians that the discipline is prior to or independent of the results of the sciences (Bealer 1982; Lowe 2002; Hawley 2006). Of course, most of the metaphysical subjects just listed are relevant to and used in the sciences. However, some, such as L. A. Paul (2012), argue that the sciences merely study the *instantiations* of these general categories, whereas metaphysics studies those categories *as such*. Similarly, Lowe (2002) argues that metaphysics is prior to science because it provides the very conceptual framework within which scientific ideas are expressed (see Kincaid 2013 for extended discussion).

The idea that metaphysics is independent from and even prior to the sciences has undergone waves of criticism, from Hume to the logical empiricists of the twentieth century (Carnap 1950; Creath 2023). This kind of criticism has once again gained new life in philosophy in recent years. One source of skepticism lies in the a priori methods those approaches to metaphysics are said to rely on, such as appeal to intuition (Ladyman and

Ross 2007; Kincaid 2013; Bryant 2017) (though see Bennett 2016). Critics argue that there is no reason to expect reality to conform to our intuitions, which are highly variable and contingent and which have evolved to serve aims unrelated to objective truth. Claims of this kind are supported by empirical work in experimental philosophy, which shows cross-cultural variations in intuitions (e.g., Rose 2020), thereby challenging the universality and authority of the intuitions on which canonical philosophy is based. In contrast, Paul (2012) defends metaphysics by arguing that it shares with science a methodology based on inference to the best explanation (IBE)—that is, a preference for theories with virtues such as simplicity and generality. Since science uses IBE and is successful in doing so, this indirectly vindicates metaphysics, which uses the same methods. However, aside from questions about whether the legitimacy of IBE survives the transition from science to metaphysics, it may in fact be false that IBE is as generally abundant in science and especially biology as Paul takes it to be (Novick 2017). If so, Paul's indirect justification for metaphysics is unfounded. Alternatively, one might regard some arguments for scientific metaphysics (in this volume and elsewhere) as implicitly resting on a kind of IBE logic, interpreted as arguing that metaphysical conclusions are what best account for the success of some particular set of scientific practices.

The preceding criticisms target the *justifications* that metaphysicians provide for their claims, arguing in various ways that those methods of justification are inadequate. Other criticisms run deeper: for some, claims about things that lie outside empirical experience, even in principle, are not just unsupported but meaningless. This kind of argument has roots in Hume's famous distinction between matters of fact and relations of ideas and was famously elaborated formally by the logical positivists in their principle of verification. It is also a major theme in American pragmatism—an important intellectual connection between Hume and the logical positivists. C. S. Peirce, for example, claimed that the Catholic doctrine of transubstantiation was not just false but meaningless precisely because it posits a fact that lies beyond all possible experience: "To talk of something as having all the sensible characters of wine, yet being in reality blood, is senseless jargon" (Peirce 1878/1935). Peirce, like many whose work he inspired, believed that metaphysics properly understood did not lie outside experience but worked *for* experience. In other words, metaphysical ideas serve to structure and organize our interactions with the world in useful ways rather than being about things that make no difference, even in principle, to those interactions.

(See Lean 2021 for a discussion of this idea in relation to contemporary biological data practices.)

In summary, scientific metaphysicians hold that if metaphysics is to be a meaningful and worthwhile pursuit, it should be based as far as possible on lessons from the sciences rather than just on a priori reflection. This view is also driven by a positive argument: since science investigates reality and is highly successful at doing so, its success-making features should be relevant evidence for what that reality is like. However, acknowledging the relevance of science to metaphysics leaves open exactly what the relationship between the two should be; that is, exactly what aspects of science are relevant to metaphysics and in what way (Hawley 2006; Kincaid 2013; Chakravartty 2013; Bausman 2023; Creath 2024). What is needed, in short, is an account of how science relates to the world such that the former can serve as evidence for the latter and that offers recommendations for how to gather and use this evidence in metaphysical discourse.

2. A METAPHYSICS BASED ON BIOLOGICAL PRACTICE?

This volume explores the intersection between the two philosophical movements outlined previously—that is, between scientific metaphysics and a practice-oriented philosophy of science. As mentioned, scientific metaphysics is motivated by science's success and considers this to be worth taking seriously when we ask what the world is like in metaphysical terms. For the most part, however, this project has restricted its attention to successful scientific *theories.* But from the practice perspective, theory is only one aspect of what makes science successful. This suggests that the practice perspective may bring attention to a vast collection of success-making factors in science that metaphysics can potentially draw on. For example, Baxter's chapter represents how a practice-based approach to scientific metaphysics opens up new questions about the metaphysical commitments of things like genome databases—a practice that has only recently received philosophical attention.

What's more, the theories on which scientific metaphysicians have focused have largely been those of physics. Ladyman and Ross (2007), for example, argue that unifying the sciences by relating their theories to those of fundamental physics is what a properly naturalized metaphysics should be for. If that is what one means by metaphysics, then either failure to relate a science to fundamental physics or finding a disunity between the sciences would invalidate their entire metaphysical project. However, there are other ways to understand the project of metaphysics that still recognize the importance of paying attention to science. On some of those ways, the biological sciences have much to offer in metaphysical discourse in their own right, in ways that don't necessarily involve relating those sciences to fundamental physics.

Biology often fails to fit metaphysical theories that are developed in relation to physics, and so it offers an important set of case studies for testing the general validity of those theories. One example is the relationship between classical and molecular genetics, which fails to fit standard models of reduction (Waters 2008; Weber 2006). Second, scientifically friendly metaphysicians might be interested in exploring what (if any) metaphysical conclusions can be drawn from traditional biological questions—questions about natural selection, intentionality and the mental, biological individuality, species, and biological information. These concepts apparently concern aspects of our reality and can be interpreted as metaphysical. They have also often been seen as metaphysical historically. What's more, those aspects are of particular importance to human society. Hence they may be worthy of close attention by metaphysicians who sympathize with John Dupré's sentiment that "biology is surely the science that addresses much of what is of greatest concern to us biological beings, and if it cannot serve as a paradigm for science, then science is a far less interesting undertaking than is generally supposed" (1995, 1). Overall, the kinds of phenomena that the biological sciences study are closer to home than and also qualitatively different from those of physics. For philosophers interested in exploring metaphysical views of the everyday biological reality we encounter, this volume is a step in that direction.

Why has this potential gone largely unrealized? Because, in general, practice-focused philosophers have taken a negative or debunking attitude toward metaphysical interpretations of scientific claims rather than aiming to refine and improve them. For example, against those casting questions about typology as metaphysical and connected to essentialism, Love (2009) argues that typological thinking in developmental biology is simply an epistemic strategy that can yield different categorizations according to different goals. Metaphysical interpretations of science, such as determinism and essentialism in biology, have also long been the target of important criticisms from a feminist perspective (Longino 1990; Dupré 1995; Gannett 1999; Haslanger 2016). What this means is that in addition to scientific metaphysics largely overlooking practice, philosophers of scientific practice have largely overlooked or been broadly critical of metaphysics. These two realms of inquiry have largely been mutually exclusive or even hostile.

As valuable as these critical views of metaphysics in science are, one may also ask whether it is possible to develop a *positive* metaphysical project that adequately accommodates their criticisms. It is time to drop the implicit assumption that showing the aims and values of scientists who generated a result is enough to undermine any further metaphysical interpretation of the result. There are, to be sure, already examples of philosophical work that do appeal to biological practice in advancing metaphysical claims. Probably the clearest example of this is John Dupré's *The Disorder of Things* (1995). There, Dupré identifies and criticizes a number of metaphysical precepts underlying discourse about science; namely, essentialism, reduction, and determinism. All of these assumptions are misplaced, he argues, because they do not square with observations about how scientists (biologists in particular) actually go about investigating the world. If we reject these precepts—as he argues we should—we instead find a metaphysics based on disunity, variety, and change. More recently, Dupré and others have defended a metaphysics based on processes over substances (Dupré and Nicholson 2018). As another example, Joseph Rouse (2002) argues that scientific practices hold the key to dissolving the conflict between the causes of nature and the norms of the social world. His arguments center around understanding humans as social organisms interacting purposefully with their environment and scientific practice as, in effect, a special case of niche construction.

Most of these works appeal to scientific practice in order to advance a particular metaphysical thesis or provide different practice-based angles on a particular metaphysical issue. The present volume's broader aim is to showcase ways in which biological practice might inform a variety of metaphysical discussions as well as explore foundational questions about whether and how inferences from biological practices to metaphysical conclusions are possible.

Ultimately, demonstrating the possibility and the value of a metaphysics based on biological practice means doing the work of addressing individual metaphysical questions from that perspective. In the next section, we discuss particular questions and concepts that are typically characterized as metaphysical and that are addressed in more or less explicit ways throughout the chapters of this volume.

3. THE NATURE OF METAPHYSICS AND SCIENTIFIC REALISM

As we've seen, there is no agreement on what counts as metaphysics: For some, metaphysics is by definition distinct from and prior to science or to empirical inquiry generally. For others, metaphysics is a post-scientific exercise of unifying scientific theories by relating them all to a common theoretical foundation such as fundamental physics in order to discover what there is. The works in this volume depart in important ways from most approaches to metaphysics: For one thing, they emphasize practice over theory. For another, they generally treat biological sciences as metaphysically interesting in their own right, independently of questions of whether and how they relate to fundamental physics. Of course, one may simply deny that these are works of metaphysics on the basis that they fail to meet one's preferred definition of the term. We aim to provide reasons why we take the approaches in this volume to be worthy of the label, even if some will not agree. Despite many differences in approach in the chapters of this volume, we see among them a common thread underlying their respective subject about what a metaphysics from biological practice involves. Here we articulate this idea and place it in context with other views.

In our view, justifying a philosophical project as metaphysics involves at least two things. First, it should be recognizably *meta*-physical rather than "merely" scientific. Of course, this doesn't mean that the two are strictly different pursuits; it may be that doing science sometimes means doing metaphysics in the process, or vice versa. (Lean [2021] takes a view to this effect in regard to digital ontologies in biology, for example.) While scientific metaphysics is by definition informed by science, it should contribute something to our understanding that is not contained in the explanatory or investigative reach of the science. Importantly, it must have an answer to the question of what a metaphysics based on science can add to our understanding that the science itself cannot provide without presuming to go "around" or "beyond" the science, which naturalistic philosophers consider to be problematic. Sometimes metaphysicians ask different questions or investigate different domains than scientists, other times it is their approach to investigating the same questions as scientists, and other times the same work can be considered scientific and metaphysical. For example, Ladyman and Ross (2007) satisfy this criterion by viewing the role of metaphysics as *unifying* diverse scientific theories. Even if such a project were to qualify as a science in itself, this second-order, unificatory goal also makes it meta-scientific while still adhering in important ways to scientific results. Other metaphysical work inquires into the implications of a part of science for the nature or reality of something. This inquiry must not be seen as extra-scientific tout court, only extra- this specific part of science, as when psychologists ask about the implications of evolutionary biology on modern human psychology.

Second, as well as being distinct from the sciences, a metaphysical project should be distinct from epistemology: there should be a sense in which the questions one is asking about science are not just about the scientists' concepts, beliefs, practices, or whatever but also about the nature of the domain they investigate. It is on this point that practice-focused philosophers have often ignored or actively distanced themselves from metaphysics, since they often take their subject matter simply to be scientific practices and social epistemology and the like rather than an attempt to articulate the nature of the world that those sciences describe. Hence the challenge for practice-focused scientific metaphysics is to justify the metaphysical import of one's claims without ignoring or glossing over the epistemic aspects, since (on the scientific metaphysics view) it is precisely those epistemic aspects and their success-making features that underwrite science's relevance to metaphysical questions.

We take most of the work in this volume to meet these criteria in the following way. First, the metaphysics undertaken here differs from scientific inquiry itself because it studies those practices in which scientists are engaged. It therefore shares its direct object of inquiry with the rest of science studies—that is, with history and social studies of science (Soler et al. 2014). An important principle of science studies is that many important aspects of science are implicit or unconscious and not well understood or even necessarily known to the scientists themselves. It is therefore a task of science studies such as philosophy to make those things explicit so that they can be understood and critically analyzed. One example is the concept of repertoires, which was developed by philosophers and sociologists to understand how successful systems of scientific practice are reproduced in new contexts (Leonelli and Ankeny 2015; Ankeny and Leonelli 2016). Note that this is a different way to work "above" science than analytic approaches to metaphysics: rather than attempting to go around science or to establish its a priori foundations, as some metaphysicians have aimed to do (see Creath 2023; Ereshefsky and Reydon 2023), the chapters in this volume stand apart from science in that they take science-in-practice as their direct *object of inquiry.*

This itself is insufficient to establish such a project as metaphysical, rather than simply metascientific or philosophical in general, because of the second criterion. That is, we also need a justification for why this sort of project concerns not just the scientific practices themselves but also the world outside those practices. The reason is that we are centrally concerned with what makes a science *successful,* and that success is partly shaped by things that are extrinsic to science itself; in particular, the world it investigates. Note that this is simply the basic motivating principle of scientific metaphysics in general—that science is relevant to metaphysics because it is successful—generalized to make both theoretical and nontheoretical practices metaphysically relevant. Many of the approaches in this volume entertain the possibility that scientific practices are successful because they *fit* aspects of reality that they encounter. Here, "fit" can be understood in engineering terms: those practices exhibit features that make them well designed to achieve particular aims in the particular environment they work in.

It is worth noting that the idea of strategies fitting their environments has become a commonplace principle in the science of machine learning—arguably a form of applied epistemology. There, it is widely accepted that there is no single best method for collecting and interpreting data that is optimal regardless of the world's structure (Wolpert and Macready 1995; Korb 2004); in other words, the success of epistemic strategies for learning about the world depends on what the world is like. The inseparability of metaphysics and epistemology is far from a new idea, then, though we take it to be particularly important here: while our focus is on successful epistemic practices, it is critical to remember that those practices are successful when and because they work well in their *external environment,* as Herbert Simon (1996) put it. We cannot ignore the role of the world in enabling successful science any more than we can ignore the role of the environment in biological adaptations.

In short, we take the work in this volume to adopt, implicitly at least, what can be called a *functional* approach (Woodward 2014; Woody 2015). That is, it supposes that scientific practices have goals and purposes, sets out to determine what those purposes are, and therefore critically evaluates the extent to which they are successful in their goals. Importantly, since an overarching goal of science is to investigate the world, what makes it successful has at least something to do with what the world is like. This view is most explicit in Ereshefsky and Reydon (2023), in which classification systems are argued to pick out "natural" kinds when the success of those systems is "grounded" in features of the world. Similarly, Lauren Ross (2023) effectively treats epistemic strategies in psychiatric genetics as solutions to the complexity of their domain of inquiry. Bausman (2023) aims directly at an analysis of this kind of inference by comparing it to similar arguments in biology that are based on claims about adaptation.

These questions about the relationship between science, epistemology, and metaphysics closely connect to the issue of scientific realism. In the broadest terms, scientific realism amounts to the idea that science aims at describing or getting at reality. Traditionally, scientific realism has been formulated in terms of true theories—or theories that describe a set of justified true beliefs (Van Fraassen 1980). Truth is standardly understood as a correspondence between what our propositions say and how the world is. For scientific realists, the success of those theories is best explained by the idea that they are at least approximately true. However, it is difficult to evaluate systems of scientific inquiry on the basis of truth from a practice-based approach to philosophy of science because much of scientific knowledge is non-propositional and, thus, is neither true nor false (Baird 2004; Waters 2014; 2017; Chang 2017). Instead, many scientific practices are better understood as *knowledge-how or knowledge-as-ability* rather than *knowledge-that or knowledge-as-information* (Chang 2017); they involve skills and abilities to act. This means that if we are to engage in reasoning about reality by observing successful practices, it should be based on a different or more general relation than truth. One way to do this may be to adapt the idea of truth-makers—the facts or states of affairs that impart truth on statements about the world—and instead talk about *use-makers,* or states of affairs that impart usefulness on scientific practices. As Otto Neurath once wrote, "statements are compared with statements, not with 'experiences,' not with a 'world' nor with anything else" (1931/1983, 53). We say that scientific statements are truth-apt and the world supplies the truth-makers. Following this, we should say that scientific practices are *use-apt* and the world supplies the *use-makers.* When a practice fits an aspect of the world to a high degree, those aspects of the world make those practices useful. Some philosophers might wish to defend a version of scientific realism constructed around a more sophisticated notion of truth, but this needn't be our only way of thinking about scientific realism.

In contrast to a focus on truth, we could instead explore how to think about scientific realism in terms of the broader idea of progress. Science makes progress whenever it helps us learn something new—whether it be a piece of propositional or practical (non-propositional) knowledge—from reality. Reality is not subject to our whim. We do not make reality by simply thinking or imagining. Instead, reality resists or frustrates our efforts to carry out our aims. Practical know-how is whatever skills and beliefs are needed to successfully engage in epistemic activities in the world. We are sympathetic to what Hasok Chang calls active scientific realism. Active scientific realism is a commitment to continually seek greater contact with reality for as many different aims as we may wish (Chang 2012). Importantly, our proposal has some important differences with Chang's view. Chang is quite skeptical of what we are calling scientific realism. Instead, he maintains that metaphysics of science is the best philosophers can achieve. At least some of the authors in this volume are more hopeful that a scientific metaphysics grounded in progress is possible.

Setting aside the status of truth and scientific realism, we can distinguish between different types of projects a philosopher of science interested in metaphysics might pursue. Following Roe (2015), Waters (2017), and others, one type of project a philosopher of science might engage in is what we call the *metaphysics of science.* This project examines the metaphysical assumptions and commitments made by a system of scientific inquiry and differs from how others have defined the project (Mumford and Tugby 2013). For example, for the developers of the kinetic theory of gases, heat is the energy of molecules in motion. Kuhn's (1962) analysis of paradigms or disciplinary matrices includes metaphysical commitments of this kind. Relative to the system of inquiry within which scientists work, the relationships and entities that characterize the inquiry can be thought of as an "internal ontology" (Gillet 2021). The metaphysics of science is a descriptive and interpretive project toward understanding how a system of scientific inquiry operates internally—according to its own logic and assumptions. As such, it need not be thought to say anything about what the world is like outside a system of inquiry without further argument. This is in contrast with what we will call *scientific metaphysics.* This project attempts to get outside a particular system of scientific inquiry to say something about what the world is like by drawing on the practice and results of science.

The metaphysics of science versus scientific metaphysics distinction is independent of an interpretation of the claims of scientific metaphysics. Scientific metaphysics claims will still be open to interpretation and different schools will interpret them differently. For example, "Heat is not a substance but molecular motion" might describe states of affairs, or it might express an attitude toward life (Carnap 1931). It might be seen as truth-apt or use-apt. Either way, metaphysical claims of this sort require substantial justification beyond internal coherence and success (Chakravartty 2010; Morrison 2011; Chang 2014; Bausman 2023). For the success of a system of scientific inquiry can be due to a variety of nonscientific factors—such as the interests, values, and social structure of a scientific community.

Importantly, on our conception, metaphysics of science is a necessary first step toward a scientific metaphysics. Before we can know whether we are justified in concluding that atoms, genes, gravitational fields, or economies have an ontological status outside the systems of inquiry from which they are described, we have to know how to interpret and understand these objects from within their systems of inquiry. Arriving at the metaphysics of a scientific project can require significant philosophical reflection on the vocabulary, activities, and social structures informing an area of inquiry. Several chapters in the volume are engaged in metaphysics of science projects. For example, Baxter's contribution aims to clarify and defend the GenBank gene concept as a useful structure for the purposes of organizing and disseminating genomic information through the National Center for Biotechnology Information's digital database system. Kaiser and Trappes clarify the NC^3 mechanisms at work in a collaborative project in which they participate titled "A Novel Synthesis of Individualization across Behavior: Niche Choice, Niche Conformation, Niche Construction." These authors maintain that the GenBank gene concept and NC^3 mechanisms have ontological character internal to the systems of inquiry that investigate and develop them. However, as Kaiser and Trappes note, we should understand the metaphysical status of such entities as "provisional" for the analyses offered in these chapters do not supply the justification required for a scientific metaphysics.

Can philosophers of science defend a scientific metaphysics, and if so, how? They have several options available to them. One possibility is perspectival realism (Giere 2010; Chirimuuta 2016; Massimi 2018). On this view, a propositional claim P is true so long as it is true according to the truth conditions of its scientific system of inquiry. For example, from the perspective of modern chemistry the statement, "water is H_2O" is true and the statement "water is HO" is false; however, from the perspective of Dalton's system, the latter statement is true (Chang 2014). An objection to perspectival realism is that it provides no means for evaluating which systems of inquiry "get things right" in a more absolute sense that antirealist accounts of science fail to supply. One proposal for resolving this problem is to evaluate the adequacy of different systems of inquiry not on the truth of propositions but on various dimensions of success—such as explanatory and predictive power, testability, manipulability, and so on (Massimi 2018). Success can be measured along multiple parameters and, unlike truth, is a matter of degree. Thus, we can compare different systems of inquiry. For some philosophers of science, greater degrees of success might be taken as an approximation for truth, whereas others, like Hasok Chang, can reject this view and just treat success as the primary aim of science.

Another possibility is to take Bill Wimsatt's (1994) view of robustness as a criterion for the reality of objects and properties. Robustness here means that an entity is accessible in a variety of independent (in the sense of probability of failure) ways. Therefore, if an entity is detectable or manipulable using independent instruments and predictable from independent theoretical assumptions, it is (probably) real. Comparing Wimsatt's view to perspectival realism, Wimsatt takes the "objectivist" step using robustness: if there are many independent reasons (models, theories, experiments, instruments, etc.) for thinking that heat is not a substance but molecular motion, then heat is molecular motion.

Finally, in keeping with the broadly pragmatic approach of this volume, we should consider not just what metaphysics *is,* in our view, but also what it is *for.* As we've seen, one interpretation of the role of scientific metaphysics is to unify the sciences with fundamental physics in order to place constraints on acceptable theories in the special sciences. While we do not feel the need to criticize this view, we believe there are other valid motivations to do scientific metaphysics. As discussed, many metaphysical questions raised about the natural world are of considerable significance to humans' understanding of ourselves and of our relationship to our reality more widely. Virtually every facet of human society—ethics, law, economics, religion, the arts, politics, and so on—involves commitments about the nature of the world we inhabit. How much and in what ways are those commitments accountable to the results of the sciences? The question of the relationship between science and metaphysics is, in fact, a question about the authority of science and its place among other types of inquiry and in society as a whole.

We see an important role for scientific metaphysics in offering clarity about the nature and extent of science's authority in our broader conceptions about the world. Ladyman and Ross vehemently deny the idea that the role of philosophy is "to try to make the world as described by science safe for someone's current political and moral preferences" (2007, 6). We wholeheartedly agree with this sentiment—science can and should be invoked to challenge moral and political beliefs if those beliefs are based on ignorance, misunderstandings or overinterpretations of scientific output. However, we see a great deal of work left to be done to determine exactly when and in what ways the results of science can be brought to bear on those other facets of human life. For example, to what extent should society's view of sex be based on biology? To answer this question, one must consider the role that sex categorizations play in biological practice; for example, in comparing and explaining reproductive strategies. From that, we can consider the various purposes for assigning people to sex categories in human society and then ask to what extent those purposes overlap or interact with those of biological practice. One can reasonably accept the importance of biological sex to biologists and the "reality" of biological sex—in other words, that sexes are natural kinds in Ereshefsky and Reydon's sense—while questioning whether society should use sex categories in the same way that biologists do. Looked at in this way, the insistence in the public sphere that "sex is biological" is in effect the claim that all of society's institutions should adopt biology's standards of sex classification. It is therefore revealed to be a normative social claim rather than a factual scientific one and should be justified and criticized accordingly.

The real world value of a practice-oriented scientific metaphysics extends even beyond challenging moral and political beliefs founded on misinterpretations of scientific knowledge. By carefully describing the conceptual and technical developments at the heart of scientific practices, philosophers position themselves to embark on a kind of project Hasok Chang calls complementary science (Chang 2004). Complementary science involves advancing alternative conceptual schemes that have been neglected, forgotten, or suppressed by scientific institutions but that have the potential to advance human understanding of the world in novel ways. Complementary science is driven by normative considerations. At this stage of inquiry, the philosopher of science may embark on what Sally Haslanger (2000) calls an analytical project, whereby one asks what work we want our concepts (such as race and gender) to do for us. Descriptive works in the history and philosophy of science necessarily build the foundation for and thus must come prior to complementary science. Philosophy of science that carefully details the conceptual and technological developments of scientific inquiry helps uncover the contingent choices scientific actors have made in the past. This is no small lesson to glean from the study of scientific metaphysics. In clarifying the ways scientific systems of practice are partially informed by the choices scientific communities make, philosophers of scientific metaphysics help identify ways in which scientific systems of practice could be otherwise. In this way, philosophers of science can bring epistemological, social, political, and ethical considerations to bear on the ways scientists engage with the world. Yet, before philosophers of science can take up complementary science, extensive descriptive work must be done. That is what much of the work in this volume strives to do.

This volume represents the view that attention to scientific practices is critical to questions about how science should constrain our wider belief systems, since it is all too easy to misinterpret the significance of theoretical claims in science if we fail to consider the practical context in which those theories operate. In short, one can only properly interpret what science *says* about the world by first understanding what science *does.*

4. CAUSALITY

There is a deep tension in the notion of causality. On the one hand, it appears to be essential to our understanding of the world: the only way we can reason about the unobserved is to posit connections behind our observations that will be repeated in future. On the other hand, we never directly observe causal relationships, only regular co-occurrences. In other words, no causal claim is logically entailed by any possible observational data. This problem is especially pressing from the point of view of scientific metaphysics. Bertrand Russell (1913) famously argued that there is no causality in fundamental physics, since its laws are all symmetrical whereas causality is asymmetric (see Ladyman and Ross 2007 for critical discussion). Importantly, the special sciences such as biology appear to be deeply committed to causality, as evidenced by their prominent appeal to causal explanation, process, mechanism, and other causal concepts. If we insist on getting our metaphysics from science and yet science merely *presumes* causality where it uses it at all, what does this mean for the idea of causality in a scientific worldview?

The shift of perspective to scientific practice has revitalized philosophical discussion of biological causation in recent decades. From the practice perspective, rather than beginning with questions about what causality "is" and then looking to scientific theories to tell us the answer, we can instead begin by analyzing causal *reasoning* and the purposes it serves in the various practical goals of science. This view of the relationship between philosophy and practice in relation to causality is neatly summarized by Dewey: "The first thinker who proclaimed that every event is effect of something and cause of something else, that every particular existence is both conditioned and condition, merely put into words the procedure of the workman, converting a mode of practice into a formula" (1958, 84). The role of philosophy, from this perspective, is to make explicit and to codify those practices that constitute science's understanding of causation.

This practice-first attitude is what motivates *interventionist* theories of causation such as that of Woodward (2003), which several chapters in this volume draw on. According to interventionism, causal reasoning is closely tied to purposes of manipulation or control: to reason about causes is to reason about how to change outcomes through actions. In other words, causal reasoning reveals the "levers" or "handles" that can be exploited (in principle) to change things in our environment. Interventionism in philosophy connects closely to sophisticated scientific work in statistics and artificial intelligence, which has developed an interventionist logic of causal reasoning (Spirtes et al. 2000; Pearl 2009). Interventionism holds that *scientific* progress has partly consisted of developing more sophisticated and elaborate ways of investigating and reasoning about these causal levers; this is what it is to develop better explanations (Ismael 2013; 2017; Woodward 2014; Ross forthcoming).

Interventionist approaches to causation in the sciences are especially useful when applied to biological and biomedical sciences. Scientific principles about the workings of biological systems are exception-ridden, contextual, and contingent, which makes it difficult to view causal reasoning in biology in relation to laws. Causal reasoning in biology therefore offers a rich testing ground for ideas about high-level and top-down causation (Wimsatt 1976; Craver and Bechtel 2007; Woodward 2008; Green and Batterman 2017; Weber 2006). Woodward argues that as well as distinguishing causes from non-causes, biologists also distinguish one cause from another along various dimensions (Woodward 2010). For example, one cause-effect relationship is more *stable* than another if it holds under a wider variety of background conditions, or under a wider range of manipulations. Importantly, these distinctions *matter to us* because they afford different types and degrees of control and prediction. This line of thinking has recently been applied to the controversy about the privileging of genes among other causes in development (Weber 2006; Waters 2007; Griffiths and Stotz 2013; Ross 2020; Baxter 2023).

Another key part of understanding the role of causal reasoning in biology is to understand how it connects to other kinds of reasoning. For example, one closely related concept is that of *mechanism*: biologists often explain biological phenomena by citing the entities and/or activities that interact to produce those phenomena (Machamer et al. 2000; Craver 2007; Glennan 2017) (though see Ross 2018). There has been much discussion in philosophy about what mechanistic explanation amounts to, how much of biology is concerned with it, and how the notion relates to other concepts such as that of interventionist causes discussed previously. Lean's (2023) present contribution discusses the relationship between causality and the concept of *information* that is widely used throughout the biological sciences. In keeping with a functional approach to understanding scientific practice, understanding the role of one type of practice means understanding how it connects to others.

For some, especially those engaged in questions of causality in analytic philosophy, these practice-focused treatments of causation may not count as metaphysical at all. It may be argued that these "merely pragmatic" considerations are quite irrelevant to the concerns of metaphysicians, who are instead interested in causality's metaphysical basis or grounding (Woodward 2015; 2017). This is of course true if one's definition of metaphysics makes it essentially irrelevant to practical concerns. However, as we have stated, a major aim of this volume is to explore the possibility of a metaphysics that *is* informed by practice. In fact, when we recognize scientific practice as the engine of success, the very possibility of a scientific metaphysics (based on our most successful science) implies the relevance of practical matters to metaphysical problems. In the case of causation, it is not unreasonable to suppose that the way a science uses causal reasoning might have something to do with what the world is like. In the case of biology, we might coherently ask whether there is something *about* biological phenomena that makes it beneficial to biologists to reason in one way rather than another, given their purposes for doing so (Lean 2023; Ross 2023; Wimsatt 2023).

5. CLASSIFICATION, NATURAL KINDS, AND PLURALISM

Scientific inquiry, as with all reasoning about the world, involves labeling and categorizing things, organizing what we observe and what we posit, into theoretical boxes. Scientific classification systems are, as Lorraine Daston (2004) puts it, "applied metaphysics" or "metaphysics in action": they make sense of our experience by positing general types of which individual things in the world are tokens. The kinds of entities and their interrelationships posited by a science are sometimes called its *ontology,* especially in the context of the formal representation of scientific data for the purposes of digital storage and sharing (Leonelli 2010; 2016; Lean 2021).

Not coincidentally, ontology also refers to the branch of metaphysics concerned with what sorts of things exist and how they are related. For a scientific metaphysician, committed as they are to basing their metaphysical theories in science, questions about ontology—about what kinds of things exist and how they fit together—can be answered by looking at how successful sciences see fit to categorize the world. From a theory-first point of view, such as that of Quine (1948), basing ontology in science means reading off the ontological commitments that scientific theories make; that is, what sorts of entity are posited, what sorts of properties they are taken to have, how these entities and their properties relate to each other, and so on. By contrast, a practice-based approach will base its ontology on classificatory schemes that organize and direct activities, techniques, and collection practices of scientists (Hacking 1983).

Whether we base ontology on theory or practice, one thing scientific metaphysicians quickly confront is that scientific pluralism is very much the norm in scientific thinking (Dupré 1995; Mitchell 2003; Kellert et al. 2006; Havstad 2018). Scientific pluralism with respect to classification is when there are multiple ways of categorizing things. Scientific pluralism can occur when different fields operate with quite different classification schemes or when one and the same field employs inherently different classification schemes (sometimes even when focusing on one and the same phenomena—see Havstad 2016). This is particularly true in the biological sciences, where widely used kind terms like “gene” and “species” appear to have multiple, often-incompatible definitions, both between and even within scientific fields (Baxter 2023; Weber 2023). There is, it seems, an apparent tension between the fact of scientific plurality and the intuition that science aims to discover the natural kinds, since the kinds posited in different sciences don’t appear to fit neatly together and thus don’t appear to consistently apply to a single reality (Chakravartty 2017).

We can understand this problem as that of the relationship between scientific ontologies, as ways of conceptualizing a domain for empirical purposes, and ontology as a metaphysical inquiry: In what sense, if at all, do the kinds posited by the sciences reflect kinds that actually exist in nature? More specifically, how, if at all, can we reconcile the plurality of scientific ontologies with some kind of unity in the world they supposedly represent? Is the unity of science something worth striving for? If so, what kind of unity, and what for?

These questions potentially have concrete practical implications, as they connect in important ways to our ideas about what science is for and how it should be evaluated and therefore to socially important issues such as policy-making (Mitchell 2003). This is particularly evident in the context of data-centric biology: the increasing emphasis on sharing and reuse of data across different research contexts creates the need for some form of agreement about data representation and labeling, which has raised important questions about the theoretical assumptions underlying data classification systems and how these differ between different disciplines and fields. At stake here are important issues about how to achieve cooperation and coordination across research communities while also respecting dissensus and the differing needs and goals of those communities (Smith et al. 2007; Leonelli 2010; 2016, Laubichler et al. 2018; Sterner et al. 2020; Lean 2021).

A way to address this problem, we believe, lies in carefully considering the way in which the varying purposes for which we categorize the world interact with the features of the world on which the satisfaction of those purposes depends. As Ereshefsky and Reydon (2023) point out, while categorization systems in science are to be evaluated by how well they serve their particular function, it is often, at least partly, the world being categorized that underwrites that success. Nevertheless, the function or purpose of that categorization is as inextricable to that justification as the aspects of the world that ground their satisfaction. By analogy, suppose we discovered a toolbox and wanted to justify why it contains that specific set of tools. No one tool can do everything, and so we need several. Yet a worker shouldn't be overladen, so one should also avoid unnecessary redundancy. There are tradeoffs to be made in this respect, but reasons can be given for the choices made. Understanding a toolkit requires reference to the sorts of objects and materials the tools are designed to work on but also to the user(s) of the tools and their aims, needs, and abilities. When we look at scientific classifications in this way, there is no conflict between scientific pluralism and the possibility of scientific metaphysics, or vice versa: the fact that we need multiple tools does not threaten the idea of a single shared reality, nor does the unity of reality demand that we throw away all but one of our tools. In short, another approach to unifying the sciences, besides relating them all to a theoretical hub of fundamental physics, is to relate them all to scientific practice—to conceive them as means for achieving a variety of ends and setting about understanding those means-ends relationships.

6. CHAPTER SUMMARIES

WIMSATT. In "Evolution and the Metabolism of Error: Biological Practice as Foundation for a Scientific Metaphysics," Bill Wimsatt offers a vision of scientific metaphysics based on two ideas: First, science as a cultural activity evolves through human organisms interacting with their environment. This engagement with the world makes a realist metaphysics possible. Second, scientists have developed useful heuristics for investigating problems similar to those faced in ontology and epistemology. Co-opting their heuristics makes learning about the metaphysics of the world easier.

Wimsatt has long championed the use of the concept of robustness as a central concept to evolution and science, and he here extends this further into philosophy. As he defines it, "Robustness is the use of multiple independent means of less than perfect reliability (often far less) to secure a net reliability higher (and often under a wider range of conditions) than possible with any single method." Robustness has ontological, epistemological, and methodological significance. The basic ontological claim concerning robustness states that real objects and properties are independently detectable. This generalizes the idea that the primary qualities of objects are those accessible from multiple sensory modalities. Robustness also ties the ontological status to the epistemic means of access and implies that we know when objects and properties are real when we can detect them with independent means.

Methodologically, Wimsatt contrasts analyzing scientific reasoning in terms of robustness with analyzing it in terms of deductively valid arguments. Robustness then leads him to lay out a new program for the philosophical analysis of science based on eleven heuristics used successfully in the sciences to learn about the world. The central heuristics are the first two: "Instead of looking for inexorable arguments, we look for robust tendencies; and for conditions under which those tendencies are more likely to be realized." This is how we analyze what and why we know what we know and learn where and when we are likely to know or learn more. "Instead of looking for truths, we study errors, and how they are made." Studying errors is the primary means by which we improve our tools and methods.

Wimsatt then gives six properties of heuristics which link together scientific heuristics with biological adaptations as evolutionary products. For example, these heuristics, like biological adaptations, are more “cost-effective” than infallible solutions to problems. These properties of heuristics and adaptations in part give reasons why the methodology based on robustness outlined previously is applicable to philosophy.

BAUSMAN. In “How to Infer Metaphysics from Scientific Practice as a Biologist Might,” William Bausman addresses perhaps the central methodological question of this volume: How do we make well-supported inferences from biological practice to metaphysics? The basis of his answer is that the relationship between a practice and the world is *fit for a purpose.* He then pursues the following analogy: successful practices are adapted to their domain in the same way that successful organisms are adapted to their environment. The fruit of this analogy is that metaphysicians can co-opt the methodology with which biologists use the traits of organisms as environmental proxies on the basis of adaptation. Painstakingly reconstructing a contemporary research program using the height of fossil mammalian teeth as a proxy for past environmental water level, he draws general lessons for establishing traits as environmental proxies on the basis of adaptation. For instance, it needs to be shown that the increased height of teeth in grazing mammalian teeth is correlated with, functionally adaptive to, and actually an adaptation to decreased environmental water levels.

Bausman then applies the lessons learned from biological practice to scientific metaphysics. Ken Waters’s (2017) argument for the no general structure thesis is a proving ground for whether metaphysicians can follow the biologists’ methodology. Several problems emerge. For instance, how can we establish a correlation between a feature of practice and the metaphysics of the world? Solving this access problem seems to require independent access to the structure of the world, which we lack. Following this, how can scientific metaphysicians support the idea that a feature of practice is functionally adaptive to some part of the world? Biological practice provides promising suggestions for how to move forward on these problems, but the prospects for surmounting them are daunting. He concludes by reflecting on the relationship between metaphysics and science. Penelope Maddy (2007) distinguishes between one-tier views where metaphysical questions are continuous with scientific practice and two-tier views where metaphysical questions float freely above science. Bausman argues that his proposal does not fit neatly into either category, aiming to scientifically answer metaphysical questions that do not directly affect scientific practice.

CREATH. It is no secret that the relationship between science and metaphysics, since they became distinct disciplines, has been unclear and often strained. In "What Was Carnap Rejecting When He Rejected Metaphysics?," Richard Creath considers an episode of this history through the eyes of Rudolf Carnap. As a figurehead of the school of logical empiricism, Carnap is notorious for his rejection of metaphysics as inimical to scientific progress. Yet since "metaphysics" means different things to different people, there is much misunderstanding of precisely what Carnap was rejecting. Creath sheds light on this question by looking at how Carnap viewed different "metaphysical" pursuits. Since he was sympathetic to some of these, and indeed engaged in them himself, we should understand what he took metaphysics to be based on the works that he explicitly criticized as such. Creath's central example is French philosopher Henri Bergson; specifically, Bergson's criticism of Einstein's theory of relativity. In short, the metaphysics of Bergson that Carnap rejected was one that takes philosophical intuition to override science on the basis that the former reaches deeper into the intrinsic nature of reality than the mere abstract symbols of scientific reasoning. Carnap rejects this metaphysics because it merely compounds disagreements rather than resolving them, since incompatible philosophies can all appeal to intuition with no way to arbitrate between them. Yet there are ways of understanding metaphysics that give it a compatible and important role in science. A Carnapian metaphysics can be one that offers pragmatic recommendations for how to organize our experience of the world. Further, Creath's discussion of Carnap opens up the exciting possibility of a metaphysics on par with the sciences that produces truth-apt, empirical claims. Creath's discussion helps set the tone for the volume by clarifying how metaphysics can coexist harmoniously with a focus on scientific practice and empirical success.

LEAN. In "Ideal Observations: Information and Causation in Biological Practice," Oliver Lean discusses the relationship between two apparently quite different ways of thinking about biological systems—namely, *causality* and *information*. Like other sciences, biologists regularly discuss biological phenomena in terms of causes and effects, processes and mechanisms. Yet along with this, it is also common to hear those phenomena described in terms of information. Information is said to be carried by genes, gathered from the environment, processed by brains, transmitted in animal signals, and so on. The question of the relationship between these two ways of describing biological phenomena reveals at its core a metaphysical puzzle descended from older controversies about the relationship between mind and world: information is sometimes thought to “float free” of its physical “substrate” in some sense while at the same time being dependent on it. Opinion among philosophers and scientists about the role and value of information-talk is sharply divided. For some, it is a useful metaphor for what are “really” just ordinary causal-physical phenomena. For others, the processing of information is precisely what *distinguishes* biological phenomena from the nonliving physical world. For others, information is metaphysically suspect and scientifically misleading and should be dispensed with in favor of more naturalistically respectable talk of physical stuff and their causes.

Lean proposes a way to resolve this controversy that takes a practice-focused approach. As discussed elsewhere in the volume, causality can be very fruitfully understood in connection with practices related to manipulation and control: discovering the causal structure of a phenomenon is to discover the ways it can be changed by intervention. Lean proposes that information can be understood in a similarly practice-focused way. However, this does not mean recasting biological information in causal language, as some have done, because information is connected to a distinct set of purposes from those of causation. That is, information-talk is appropriate when the aim is to understand how living things solve certain functional problems—problems like how to adapt behavior to one’s external environment, to other organisms, or to other subsystems of the same organism. With this in mind, Lean sketches a framework for informational thinking that is analogous and complementary to Woodward’s (2003; 2010) theory of causal reasoning: where Woodward characterizes causal claims in terms of control through “ideal interventions,” Lean characterizes informational claims in terms of coordination through *ideal observations*. Causality and information are related by the systems of practices to which each is connected, which are importantly distinct but intricately related to each other.

KAISER AND TRAPPES. Mechanisms are a pervasive structure in the biological world and for this reason have received much attention from philosophers of science. Philosophical attention has focused on molecular mechanisms (such as protein synthesis, gene expression, and neuronal transmission) and mechanisms of natural selection and ecology. However, in “Individual-Level Mechanisms in Ecology and Evolution” Marie Kaiser and Rose Trappes wish to characterize and defend another set of mechanisms under investigation by a group of behavioral and evolutionary ecologists at the Collaboratory Research Centre (CRC). This set of mechanisms are distinct from the cases previous philosophers have studied in that they operate at the individual organism level instead of at population or sub-organismal levels. "Individual-level mechanisms" involve a focal individual whose behaviors and interactions with their biotic and abiotic environment bring about a match between the individual's phenotype and its environment. The character an individual's interaction takes determines whether the mechanism is one of three types—niche construction, niche choice, or niche conformance. Collectively, this set of mechanisms are referred to as NC^3 mechanisms.

Kaiser and Trappes employ a novel methodology in their study of NC^3 mechanisms. As collaborators on the CRC project, Kaiser and Trappes have unique access to the epistemic practices of the scientists in the research group. They employ a variety of empirical approaches to describe and interpret NC^3 mechanisms as the researchers understand them—such as analysis of research grants, lectures, and publications as well as qualitative interviews and questionnaires. Their findings demonstrate a consensus (developed over the course of the research program) on the use and meaning of the concept "mechanism" by investigators. Investigators justify their adoption of a mechanism concept by appealing to causal interactions, processes, and complex organization as important ingredients for explaining how specific outcomes obtain. Kaiser and Trappes point out that these reasons happen to accord well with how the New Mechanists understand the concept. They argue that their analysis of NC^3 mechanisms involves formulating tentative metaphysical claims about the ontology at work in the CRC research program. Claims about NC^3 mechanisms are claims about what the world is like, which kinds of entities exist, and the nature of such entities. They implicitly recognize the further justification required to assert metaphysical claims in the sense we described previously as scientific metaphysics.

BAXTER. Scientific pluralism is a thesis that has been increasingly defended by philosophers of science. Roughly, scientific pluralism is the view that the world scientists investigate is characterized by a number of local, irreducible frameworks that feature incommensurable (in some sense) ontologies. Scientific pluralism is a thesis that has been advanced by philosophers of science concerning gene concepts in classical and molecular biology (Waters 1994; 2004; Griffiths and Stotz 2006; Weber 2023). Scientific pluralism prompts a variety of questions about the units of philosophical analysis. In "Just How Messy Is the World?," Baxter investigates how many distinct frameworks are under investigation in contemporary molecular genetics and the scope of explanatory and investigative significance for any given framework. She argues that the pluralism of gene concepts in contemporary molecular biology is more radical than what has thus far been characterized by philosophers of science.

Baxter's analysis draws on the individuation and annotation practices of database curators to describe and interpret the GenBank gene concept at work in the National Center for Biotechnology's digital database. In doing so, she demonstrates that genomicists employ a capacious concept that counts nucleic acid sequences as molecular genes that have been omitted from other molecular gene concepts (such as Waters 1994 and Griffiths and Stotz 2006). She argues that philosophers of science have mischaracterized scientific pluralism in genetics in two ways. First, they have undercounted the number of incommensurable gene concepts at work in contemporary molecular biology. The number of entities geneticists consider as molecular genes is actually greater than what philosophers of science have acknowledged. Second, philosophers of science have also mischaracterized the explanatory and investigative scope of molecular genes. The GenBank gene concept individuates molecular genes according to their phenotypic effects—not merely by the biomolecules whose information they encode.

Provided one is justified in inferring something about the structure of the world from the ontological commitments of geneticists—as Waters (2017) presupposes—then Baxter's discussion shows that the world is even messier than what philosophers like Waters have appreciated.

WEBER. What happens to an older science when a newer science emerges and appears to supersede the former, as in the case of, say, Newtonian and quantum mechanics? A common temptation among philosophers and scientists has been to say that the newer science has reduced the older one. Philosophers have provided various models for scientific reduction. However, in "The Reduction of Classical Experimental Embryology to Molecular Developmental Biology: A Tale of Three Sciences," Weber argues that existing accounts of reduction in philosophy simply cannot account for the relationship between classical experimental embryology and molecular biology. Classical embryology and molecular biology don't feature many (if any) fundamental laws with broad explanatory scope. This makes the case of classical embryology and molecular biology hard to accommodate by models of reduction. Instead, Weber concludes that Jaegwon Kim's (2007) account holds the most promise of accounting for the case of classical embryology and molecular biology. Weber examines the history of the organizer concept of classical embryology to demonstrate that this concept's relationship to molecular biology cannot be characterized as one of reduction in Kim's sense.

More importantly, Weber contends it was hardly the theoretical insights that the organizer concept facilitated that account for its success. The organizer concept introduced by Hans Spemann and Hilde Mangold in the early twentieth century emerged from experimental work whereby they transplanted a bit of embryonic tissue from one species of newt to another. The transplant appeared to induce the growth of another body. According to Weber, the explanatory and causal significance of the organizer concept was, at best, modest. There was much speculation among scientists with little progress over the physical realizers of the organizer concept. Nevertheless, the organizer concept is crucial to developmental biology. Why might this be? Weber proposes that what accounts for the success of the organizer concept are the set of experimental practices used to investigate developmental processes. Although the organizer concept is not reducible to the molecular level, its experimental practices continue to live on in some form in contemporary molecular biology. Even though the methods of classical experimental embryology operate at a higher level than molecular biology—for example, the cellular—methods like tissue transplantation have been integrated with contemporary methods that operate at the lower, molecular level.

Weber's discussion leads us to a very different picture of what happened with the transition from classical embryology to molecular biology than what Kim's model suggests. Instead of reduction, we have what Weber calls *inter-level investigative practice*. This framework characterizes the combination and integration of experimental interventions of an older science that occur at one level (or set of levels)—say, the whole organism, embryonic tissues, or cells—with more contemporary experimental methods that occur at different levels. Weber's idea of inter-level investigative practice represents a substantial shift in the way philosophers should think about the transition from one science to another.

ROSS. In "Explanation in Contexts of Causal Complexity: Lessons from Psychiatric Genetics," Lauren Ross discusses efforts to uncover the genetic causes of psychiatric illness. Many argue that psychiatry is in a state of crisis or immaturity: unlike somatic ailments, little progress appears to have been made in understanding the genetic causes of psychiatric disease. According to some, this shows that the genetic level is simply the wrong level at which to understand psychiatric disorders. Ross offers a new diagnosis of the controversy. First, the apparent immaturity of psychiatric genetics is at least partly because of the nature of its subject. Psychiatric illnesses are highly complex in two ways: single instances of disease tend to have multiple genetic contributors, and the causes of a disease vary widely from one instance to another. Second, despite this, scientists are finding ways to overcome the challenges that their domain presents to them. As scientists work to make their practices more fit and useful, it is important for the philosopher to consider both how the world constrains and frustrates the efforts of scientists to investigate it and what we can learn about the world from looking at practices. Ross's discussion is a rich example of how the peculiar complexity of biological systems present challenges for scientific attempts to explain them—even to classify and categorize them in the first place—and the strategies scientists use to surmount these challenges. This perspective is pragmatic, a matter of fitting one's investigative strategy to the nature of the thing being investigated given one's purposes for doing so and shows that different strategies may be needed to fit different kinds of causal complexity.

ERESHEFSKY AND REYDON. In "The Grounded Functionality Account of Natural Kinds," Marc Ereshefsky and Thomas Reydon offer a practice-oriented view of the problem of natural kinds. It is often said that science aims to classify things in the natural world according to how the natural world itself is classified. For example, there are facts of the matter about what species exist and biology's task is to correctly assign organisms to species according to those facts. Philosophers have offered several theories of what these natural kinds are that science supposedly aims to discover and represent in its classification systems. Ereshefsky and Reydon argue that existing theories fail in at least one of two ways. Some hinge on a priori matters such as whether natural kinds are universals and what kind of universals they are. These accounts fail, the authors argue, because they offer no clues about how and why scientists choose certain classification systems over others; that is, for what makes certain classification systems successful. Other theories rightly aim to account for the scientific uses of classification systems of scientific aims such as prediction but fail to account for the diversity of purposes for which scientists develop classifications. Ereshefsky and Reydon propose a grounded functionality account (GFA) of natural kinds that solves these problems. On this account, a classification scheme is to be judged solely by how well it serves the aims (epistemic or otherwise) for which it is designed. To avoid admitting too many things, such as arbitrary conventions or pure social constructs, there is a further criterion: Crucially, the kinds in the classification are *natural* kinds when the serving of those aims depends at least partly on some feature of the world that the classification system is about. The authors argue this account sidesteps the growing skepticism about the idea of natural kinds. They identify a broad agreement among biologists that the difference between natural and nonnatural is important. That is, our classification systems should in some way be grounded in the world or, rather, in the language of the GFA. The disagreements that arise are simply about which aspects of the world should ground their classifications.

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