



# Modal inferences in science: a tale of two epistemologies

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## Abstract

Recent epistemology of modality has seen a growing trend towards metaphysics-first approaches. Contrastingly, this paper offers a more philosophically modest account of justifying modal claims, focusing on the practices of scientific modal inferences. Two ways of making such inferences are identified and analyzed: actualist-manipulationist modality (AM) and relative modality (RM). In AM, what is observed to be or not to be the case in actuality or under manipulations, allows us to make modal inferences. AM-based inferences are fallible, but the same holds for practically all empirical inquiry. In RM, modal inferences are evaluated relative to what is kept fixed in a system, like a theory or a model. RM-based inferences are more certain but framework-dependent. While elements from both AM and RM can be found in some existing accounts of modality, it is worth highlighting them in their own right and isolating their features for closer scrutiny. This helps to establish their relevant epistemologies that are free from some strong philosophical assumptions often attached to them in the literature. We close by showing how combining these two routes amounts to a view that accounts for a rich variety of modal inferences in science.

**Keywords** Epistemology of modality · Possibility · Necessity · Scientific inference · Relative modality · Manipulation

## 1 Introduction

The epistemology of modality<sup>1</sup> has been one of the prevailing themes in contemporary philosophy (see, e.g., Fischer & Leon, 2017; Divers, 2002; Hale, 2013; Mallozzi,

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<sup>1</sup>The epistemology of modality is often called “modal epistemology” (see, e.g., Fischer & Leon, 2017). However, we only use the expression “the epistemology of modality” because “modal epistemology” also refers to a branch of epistemology that analyses epistemic concepts in modal terms.

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2021b; Williamson, 2007). By observing the actual world, how can we justify inferences about what is possible, necessary, contingent, or impossible? It is often thought that a satisfactory account of modal knowledge requires making non-trivial—usually metaphysical—commitments. But the next question is, of course, how can we justify those? Many existing accounts of modality face considerable challenges, and there is a huge dissent among philosophers on which, if any, of them is the right one.

The purpose of this paper is to offer a more philosophically modest epistemology of modality that nevertheless gives a satisfactory description of real-life modal reasoning. Contrary to most philosophical accounts of modality, we focus explicitly on modal claims made in science. Rather than starting with strong philosophical assumptions (see, e.g., Lewis, 1986; Chalmers, 2002; Lowe, 2012; Hale, 2013; Mallozzi, 2021a; Kment, 2021a), we feel that the epistemology of modality should benefit from paying closer attention to the scientific practice of constructing and evaluating modal inferences. The reasons for this are twofold. First, we think science is the most epistemically successful way of gaining knowledge, and many of the most interesting modal questions are either scientific (e.g., Marshall, 2008) or importantly tied to scientific results (e.g., Dennett, 1984). Second, we want an analysis of modality that concerns the kinds of modal inferences that are actually made in real life and so can be held empirically accountable. The context of such inferences is often scientific, especially when they are rigorously scrutinized.

To that end, we are offering a metaphysically modest account of how modal knowledge is gained that nevertheless gives a satisfactory description of the way modal beliefs are formulated in science. The aim is not to construct a detailed methodology or settle rivalries between particular scientific modal inferences or hypotheses but rather to appraise the general types of justifying such inferences. While there has been a recent interest amongst philosophers of science to understand the modal dimension of inquiry in areas like biology, physics, and scientific modeling practices (e.g., Grüne-Yanoff, 2013; Koskinen, 2017; Massimi, 2019; Verreault-Julien, 2019), the aim of this paper is to provide a more general “all-purpose” epistemology of scientific modality. This includes especially so-called natural or nomological modalities, but also logical, epistemic, and possibly other types. We suggest that the picture offered here naturally extends to ordinary, everyday modal reasoning. However, we do not make demands for any dedicatedly metaphysical modalities that (perhaps) go beyond what is practiced in the sciences—the possible handling of any of them by our account should be considered a happy corollary.

We begin by dissecting the philosophical tradition on the epistemology of modality by identifying and explicating two means for making justified modal inferences. The first, a posteriori way that we call *actualist-manipulationist modality* (AM), is based on the widely accepted actuality-to-possibility principle (Hanrahan, 2017; Vaidya, 2015). Here, what is observed to be or *not* to be the case in actuality or under manipulations allows us to make modal inferences. Often such inferences are ampliative. The inferences thus made are fallible, but the same holds for practically all inferences in the empirical domain. (For a similar view, see Roca-Royes, 2017.)

The second, a priori way, is founded on the idea of *relative modality* (RM). In relative modality, modal inferences are made and evaluated relative to a system *S*. Claims contradicting what is accepted, fixed, or implied in a system are impossible

within that system. Respectively, claims that can be accepted within the system without contradiction are possible. Necessary claims are such that their negation would cause a contradiction, and so on. (For related views, see Quine, 1982, p. 121; Melia, 2003, pp. 15–18; Girle, 2003, pp. 96–97; Fischer, 2016, 2017.)

While elements from both AM and RM can be found in some existing philosophical accounts of modality, we feel it is worth highlighting them in their own right and isolating their features for closer scrutiny. This helps us establish their relevant epistemologies and free them of some assumptions often attached to them in the literature that we consider unnecessary. Based on prevalent scientific practice, we then show that there is an important bridge between these two routes to making modal inferences: usually, what is kept fixed in a given system, especially in scientific investigation, is informed by what is discovered earlier through manipulations. Moreover, in scientific modelling, relative modalities suggest places for future manipulations in the world, leading to an iterative process of modal reasoning and the refinement of further modal inferences. Together, this amounts to a view that accounts for a rich variety of modal inferences in science without the need to commit to strong philosophical doctrines. The paper is structured as follows. Section 2 introduces the state of the art of the current epistemology of modality and situates our view in this context. In Sect. 3, we present a way of making modal inferences in an actualist-manipulationist way (AM), building on the actuality-to-possibility principle. Section 4 deals with relative modality (RM) as a way of making modal inferences. Here we show that theoretical knowledge about modalities can be understood relative to a framework. We also give a way of evaluating counterfactual claims. The relationship between the two epistemologies of AM and RM is the topic of Sect. 5. Finally, in the last section, we offer our conclusions.

## 2 Setting the stage

Recent epistemology of modality has seen a growing trend towards metaphysics-first approaches. It is worth quoting from the introduction to a recent special issue on the epistemology of modality in *Synthese* (Mallozzi, 2021b, p. S1841):

[F]our features [...] largely characterize the latest literature, and the papers in the present collection in particular: (i) an endorsement of the importance of essentialism; (ii) a shift to a ‘metaphysics-first’ approach to modal epistemology; (iii) a focus on metaphysical modality as opposed to other kinds of modality; and (iv) a preference for non-uniform modal epistemology.

The present paper goes against this trend—with the possible exception of (iv). But what does it mean to advocate a “metaphysics-first” epistemology of modality? Or to focus one’s interest specifically on metaphysical modality?

Non-logical modalities are typically divided into two main categories: objective and epistemic (Williamson, 2017). While the former concerns objective reality that is at least in some important sense mind-independent, the latter is explicitly taken to represent modalities as they pertain to particular epistemic agents with their limited, sometimes even highly distorted, sets of beliefs. In many ordinary and scientific cases, the distinction between objective and epistemic modalities is unproblematic.

Its pragmatic motivation should similarly be easy to appreciate. It is an objective fact of the world that it is possible for it to snow in London in June. However, this fact is obviously independent of the beliefs of any particular agent, and it is even quite easy to imagine how someone might believe that the opposite is true, namely, that it is impossible for it to snow in London during summer. Perhaps more typically, the relationship between epistemic and objective modality is the other way around: given our current limited knowledge, we might think that something is possible, only to find out later that this is not the case when more information is revealed about the state of the world.

In philosophical contexts, objective modality is often further divided into natural (or empirical) and metaphysical modalities. While natural modalities have to do with the kinds of modal facts that can be revealed by empirical investigation, metaphysical modalities can go beyond these. The exact division between natural and metaphysical modalities is far from clear. Indeed, there is substantial dissent among metaphysicians about the nature and extent of metaphysical modalities (see, e.g., van Inwagen, 1998; Hale, 2013; Mallozzi, 2021b). Should we identify metaphysical modality with natural modality, or does it form its own distinct modal sphere?<sup>2</sup> Despite its controversial status, many philosophers have focused mostly on metaphysical modality, often even in isolation (Williamson, 2017, p. 415).

Many also see in metaphysical theories the key to solving the epistemological questions concerning modalities. Examples include grounding modal knowledge on essences (Hale, 2013; Kment, 2021a; Lowe, 2012; Mallozzi, 2021a), being committed to a form of modal realism (Lewis, 1986), or truth-indicative modal imagination (Berto, 2017; Chalmers, 2002, 2010; Ichikawa & Jarvis, 2012; Kung, 2010; Yablo, 1993). But this seems to put the cart before the horse, for it assumes that in order to know such ordinary modal facts like “it is possible to break a teacup” or scientific modal claims like “superluminal signaling is impossible”, we would need a metaphysical account of the relevant aspects of the world.<sup>3</sup> Now, it seems clear that we do have modal knowledge about ordinary and scientific matters. But, as the disagreements in recent epistemology of modality attest (e.g., Priest, 2021; Wang, 2021), it is far less clear that we possess the required kind of metaphysical knowledge.<sup>4</sup> One might point out that many of these metaphysical approaches aim at giving an account of our knowledge of metaphysical modality, and, due to this, they are distinct from theories concerning natural modalities. Though there is some truth in this, the issue is not so simple. For instance, metaphysicians usually take metaphysical necessity to be stronger than natural necessity. Therefore, if something is metaphysically necessary, then it is also

<sup>2</sup> Shoemaker (1998) argues that physical and metaphysical modalities coincide, and the proponents of nomological necessitarianism—like Armstrong (2010), Latham (2011), Maudlin (2007), and Psillos (2009)—suggest that natural laws are metaphysically necessary.

<sup>3</sup> Optionally one could fully separate epistemological questions about natural modalities from those concerning metaphysical modalities, thus rendering said metaphysical questions irrelevant for scientific and everyday matters.

<sup>4</sup> Roca-Royes makes a somewhat similar statement. According to her, we possess the modal knowledge that the wooden table in her office can break. But it is not at all as clear that we have knowledge of what properties, if any, are essential to it. (Roca-Royes, 2017, p. 223.).

naturally necessary. (See, e.g., Williamson, 2016.) Thus, it is not possible to handle these two fields of modality as being completely separate.

To be fair, there have also been views on the epistemology of modality that take a more neutral approach (e.g., Bueno & Shalkowski, 2015; Fischer, 2016, 2017; Roca-Royes, 2017). Several contributions have also taken scientific results and practices seriously. For example, in his recent paper “Modality as a Subject for Science”, Williamson (2017) discusses scientific modalities at some length. However, his main motivation is to study scientific modality to learn new insights about the limitation and problematic nature of metaphysical modality. We agree with Williamson on the importance of science when it comes to evaluating modal claims. However, we do not presume any privileged metaphysical domain that we want to learn more about. Rather, we want to look for the kinds of modal claims that are actually being made in the sciences and give our best epistemic account for them.

As a pragmatic first approximation, we think the goal of scientific modal inferences is most naturally couched out in terms of *natural objective modalities*. However, we do not want to make any far-reaching assumptions about the nature of this domain beyond what is revealed to us by science itself. Of course, science ultimately is an epistemic enterprise, and our access to objective modal facts happens through epistemic means. As said, we think the justification for distinguishing between objective and epistemic modalities is pragmatic. As such, we do not demand that there needs to be some deep philosophical gulf between these, even if their respective formal apparati differ. Neither do we rule out any other options for modal targets apriori. In fact, a case can be made easily to include also pure logical modality which is often treated as its own separate category. As a branch of science, formal logic seems the best discipline to deal with this area of modality.

Epistemologies of modality have usually been divided between *rationalist* (or a priori) and *empiricist* (or a posteriori) approaches. Of the two, rationalist epistemologies have thus far been vastly more popular (for references, see, e.g., Roca-Royes, 2017; Tahko, 2017). Our view exemplifies both of these stances. We build on and contrast our argument especially with those of Roca-Royes (2017), Bueno and Shalkowski (2015), and Fischer (2016, 2017), since these seem to come closest to our own views. We present two parallel epistemologies for making inferences about modalities that exhibit predominantly a priori and a posteriori elements, respectively. However, this seemingly *non-uniform epistemic architecture* (see Mallozzi, 2021b) is later systematized as we show how these two routes are often importantly connected when scientists make modal inferences.

### 3 Actualist-manipulationist modal inferences

We will start with a way of making modal inferences that is based on actuality. These kinds of modal inferences are mainly a posteriori. This form of modal inferring is based on the actuality-to-possibility principle, which is exceptionally widely accepted among philosophers (Hanrahan, 2017; Vaidya, 2015). The idea is that what is actual is also possible. For if it were impossible, it would not be actual in the first place. However, one should note that this only allows for inferences about possibilities—and actualized ones

at that. Nevertheless, we claim that the actuality-to-possibility principle also enables making inferences of other modal categories, like necessities and contingencies.

Bueno and Shalkowski (2015, p. 678) claim that the actuality-to-possibility principle is based on another more elementary *epistemic* principle. According to it, grounds for justifying some claim are sufficient for justifying another weaker claim that the stronger claim entails. Because any claim, say “ $p$ ”, is stronger than the claim “ $p$  is possible” in the sense that  $p$  entails  $\Diamond p$ , any grounds for justifying “ $p$ ” suffice for justifying “ $p$  is possible”. Since Bueno and Shalkowski (2015, p. 678) treat relative weakness informally, it is difficult to say what this epistemic principle exactly amounts to.<sup>5</sup> In principle, we do not have huge problems with it, but we think it is more than is needed. Instead, we propose that the actuality-to-possibility principle is best understood as a semantic or linguistic one: it describes certain uses of the words “actual” and “possible” in English and in other languages, including formal languages, that contain the same or similar predicates. This comes close to the idea of *modal normativism*, which “sees the basic function of modal discourse as giving us perspicuous ways of conveying, reasoning with, and renegotiating semantic rules” (Thomasson, 2021). It is also important to note that sometimes the word “possibility” is not even used in this fashion. Instead, it might refer to something like non-actualized potentiality. This naturally affects the validity of the inference from “ $p$ ” to “ $p$  is possible” because when something is actual, it is no longer a non-actualized potentiality. Opting one or the other of these usages seems to be a pragmatic choice.<sup>6</sup>

How is the actuality-to-possibility principle applied in practice? One way of finding out whether something is contingent is by observing that it and its negation have both been actualized. For instance, it was contingent that a teacup was located at a corner of a desk. This can be inferred from the fact that it is now located in another place.<sup>7</sup> Again this only tells of actualized contingencies. As an example, most are inclined to accept it as in some sense contingent that Napoleon lost the battle of Waterloo. However, since Napoleon never actually won the battle, this method by itself does not allow us to infer that his defeat was contingent. And the same problem emerges even worse when it comes to necessity and impossibility since one cannot directly see whether something is necessary or impossible. So, pure appeal to actuality does not exhaust our knowledge of modalities—something more is needed.

Roca-Royes (2017) has argued that we can obtain modal knowledge of non-actualized possibilities by inductive inference (see also Hawke, 2011; Leon, 2017).

<sup>5</sup> Indeed, the weakness of the claims seems to be either irrelevant or redundant here as long as we know that  $p$  entails  $\Diamond p$ . For example, one could think that  $\Diamond q$  is also informally weaker than  $p$ , but this would not mean that  $p$  entails  $\Diamond q$ . Also, any proposition entails itself, so strict weakness is not required anyway.

<sup>6</sup> Vetter (2020) has recently written about non-actualized potentiality. Though she does not approach it from a semantic perspective, as we do here, but, instead, from a metaphysical one.

<sup>7</sup> According to necessitarianism all truths are necessarily true (Lin, 2012, p. 418). So, whatever happens at any given time is necessary, and, a fortiori, it was necessary that the teacup was located at the corner of the desk at that specific time. Now, of course, the fact that the cup was moved is not yet proof that necessitarianism is false. However, it does show that it was not necessary for the teacup to be always located at that place. For it was possible for the teacup to be at one place and later at another. This is the kind of knowledge of natural or empirical possibility that one can achieve with the actuality-to-possibility principle. The truth of such metaphysical doctrines as necessitarianism is something we do not wish to take a stance on.

Her view is roughly the following: one can make generalizations of actualized *de re* possibilities to other similar entities. Take a teacup. If a given teacup is shattered, it is possible for it to shatter. Now, another teacup is *similar* to the shattered one, and thus we reason that it is possible for it too to shatter. Roca-Royes' model is open to an objection: did we make the correct generalizations from appropriate similarities? What if we had inferred from the fact that the teacup is white, the general claim that it is possible for all *white* objects to shatter?<sup>8</sup> But this is just the problem of induction. One would hope that giving a satisfactory epistemology of modal inferences does not require one to solve that as well.<sup>9</sup> Still, there are better and worse cases of induction, and it would behoove us to say something about how to go about making better inductive generalizations. This is where empirical testing comes to play. We can test the shatterability of white objects by, for instance, painting objects known not to shatter white in order to see whether whiteness was the key to shatterability. Similarly, we can do tests on the shapes and materials of objects to see which of these, if any, have an impact on the possibility of them shattering.<sup>10</sup> So, our inductive generalizations are often based on the method of trial and error, at least at the beginning of the inquiry. There is no need to talk about essences since they (if there are any) need not be in play at the practical level. In the case of the teacups, no assumption of a shared essence was made. What was enough was to pick any similarity, then make predictions, and then test them. Note, however, that we do not deny that there are essences. Essences may or may not exist. We merely point out that one does not need to know that those properties, which render teacups shatterable, are essential to them. It is sufficient that teacups simply have those properties.

Thus far, we have only dealt with possibility and contingency. What about necessity and impossibility? That something is actual does not, in itself, tell us that it is necessary. By the same token, that something is not actual, and has not yet been actualized, is not a sufficient reason to think that it is impossible. We suggest that one may bridge the gap between the actual and the necessary (or the non-actual and the impossible) by employing *manipulations*.<sup>11</sup> This means that in order to find out whether something, say *X*, is necessary, through empirical means, one must try to bring about a state of affairs where *X* is not the case. This is based on the idea that if something is necessary, then no manipulation can change it. While trying to realize not-*X*, one often should try a variety of different manipulations in order to avoid too hasty inductive generalizations. Impossibility is merely a flipside of the same coin: if something is impossible, then its negation is necessary. Thus, no manipulation can actualize that which is impossible.

<sup>8</sup> We are grateful to Sanna Mattila for pointing out this possibility of error.

<sup>9</sup> Whether our inductive generalizations are good is something we learn through bitter experience and not by first having the metaphysical structure of the world in hand (see Ladyman & Ross, 2007, p. 106). If one starts as a sceptic regarding induction, one will be hard-pressed to ever get to a place where one could let go of such skepticism.

<sup>10</sup> Note that we have not given an *analysis* of the disposition *shatterable* but merely a way of figuring out whether an object is shatterable. Since this is the case, we need not take any sides in metaphysical debates about the nature of dispositions, such as whether they are “single-track” or “multi-track” dispositions, what their specificity or context-dependence is, and so on (see, e.g., Vetter, 2015, ch. 2).

<sup>11</sup> We use a non-anthropocentric notion of manipulation that is not tied to the intentions of human agents (see, e.g., Woodward, 2003, pp. 103–104). We thank an anonymous reviewer for raising this point.

As a toy example, think of a situation where one is trying to figure out whether an object is breakable or not, that is, whether it is possible or impossible to break it. (Remember that if it is impossible to break the object, then it necessarily remains intact.) One could go about this task by attempting a number of manipulations aimed at breaking the object: smashing it, asking others to help destroy it, using machines or explosives, coloring it white (recall the teacup), and so on. If such manipulations fail to break the object, one can make the ampliative inference that it is impossible to break it. To be sure, this conclusion is fallible. Nonetheless, it is reasonable to say that such attempted manipulations would give us information about the modal properties of the given state of affairs. In fact, this is how necessity or impossibility claims are often made in science, as we will show in this and the next two sections.

Let us take stock of what has been thus far established about the actualist-manipulationist account. AM inferences can give us knowledge of natural or empirical modalities. Therefore, it does not, for instance, offer information concerning metaphysical modalities—if they are separate from natural modality. To put it explicitly,  $X$  is

- (1) possible, iff  $X$  has been actualised,
- (2) necessary, iff no manipulation can alter  $X$ ,
- (3) impossible, iff no manipulation can realize  $X$ , and
- (4) contingent, iff  $X$  and not- $X$  have both been actualised.

Using Roca-Royesian inferences from similarities, one is able to extend inferences obtained about necessity and impossibility in singular cases—cases like the breakability of an object in our toy example—to other situations that are relevantly similar. Hence, assume that we encounter another object, similar to the unbreakable one, and we wonder whether that too has the same modal properties. Still, we are unwilling to try all the same manipulations as we did before. (Perhaps we are exhausted from our previous efforts or simply out of white paint.) Here, however, we have another option. We can simply observe the properties of the two objects and see if they are similar in some way that distinguishes both of them from objects that are known to break.

At this point, it is good to note a few things concerning our concept of manipulation. First, this way of gaining knowledge on necessity and impossibility is not a reductionist one since “manipulation” is arguably an implicit modal concept. After all, on the one hand, the very idea of manipulation implies the *possibility* of change, and, on the other, the idea that something might resist our manipulations implies that change might be *impossible*. Hence, we are not offering a reductionist analysis of modal knowledge. Second, manipulations need not be made by humans. So, for instance, a meteor hitting an object and not breaking it will support our inference that it is impossible to break.<sup>12</sup>

Manipulations are a principal tool for making modal inferences in science. This is not always straightforward, as the experiments they constitute are often riddled with uncertainties and underdetermined options for inference-making. However, being related by definitional stipulations, modal notions provide interconnected inferential

<sup>12</sup> Woodward has made a similar concession regarding his theory of causal explanation. He uses in his analysis the concept of manipulation, which is a causal concept, and hence his account is likewise non-reductionist (Woodward, 2003, p. 21).

avenues that are simple to navigate conceptually. Friedrich Wöhler's (1828) synthesis of ammonium cyanate into urea showed that it is possible to synthesize organic molecules in an inorganic way (Wöhler, 1828). Going by the actuality-to-possibility principle, Wöhler could deductively show only the possibility of the token instances of molecules that he actually managed to produce. However, because his experiment was in the context of a larger scientific debate, the result could be used as an argument against vitalism: to show that living systems were *not necessary* to produce organic matter. Thus, it concerned not only the possible existence of a particular instance of molecules but rather the possible types of producing them. If we assume that the experiment itself was conducted and recorded successfully and grant a suitably strong empirical formulation of the principle of *élan vital*, this inference against vitalism is logically valid even without further ampliative resources. Contrary to widely held belief, however, it also took further experiments, like Kolbe's 1845 conversion of carbon disulfide to acetic acid, to convince the opposing camp of the robustness of the possibility of inorganic-to-organic transformations. This was because there were certain unclaritys regarding the origin of Wöhler's substances, more precisely whether they could be regarded as purely inorganic or not (Toby, 2000). What kinds of modal inferences a manipulation allows for beyond token actuality-to-possibility claims—its larger “modal extent”—is typically context-sensitive and not reducible to any single element of the test-setting.

It is worth noting that the actualist-manipulationist account of modal inferences can also account for *counterfactual* inferences. To see this, suppose that we do some manipulations and find, say, that if we bring about *X*, then *Y* follows. This not only allows for the inference that *X* and *Y* are possible, but also that if *X* would be the case, then *Y* would also be the case, a counterfactual inference. Let us take a simple example. In August 1928, physician Alexander Fleming left some bacterial samples in his laboratory before leaving for a vacation. Upon his return, Fleming noticed that one of the culture plates had been left open. It was infested with mould, and bacteria would not grow around the mould. This discovery eventually led to the development of penicillin. (Arseculeratne & Arseculeratne, 2017.) Based on the anecdote, one can formulate the following simple counterfactual: “If the mould *Penicillium rubens* would be added to a Petri dish, then a number of bacteria would not grow in proximity to the fungus.”<sup>13</sup> Here we can see that empirical observation can license a counterfactual inference.

There is nothing surprising here. Indeed if we accept a counterfactual theory of causal explanation, the very possibility of manipulation will *entail* a counterfactual inference, as shown by Pearl (2009) and Woodward (2003). After all, a counterfactual theory of causal explanation is built upon the idea that the information required in causal explanation is counterfactual and can be discovered through manipulation—even when actual manipulations are not viable (Woodward, 2003, pp. 10–11).

The actualist-manipulationist account of making modal inferences is able to give information only about *empirical* or *natural modalities*. That is, they only tell us about the modalities of the *real* or *actual* world. This means that modal claims further

<sup>13</sup> Penicillin was actually discovered already before Fleming, but the earlier discoveries had been forgotten (Arseculeratne & Arseculeratne, 2017). In addition, Fleming erroneously thought that the mould he had discovered was *Penicillium rubrum* when, in fact, it was *Penicillium rubens* (Houbraken et al., 2011).

removed from empirical access, like perhaps those concerning metaphysical modality, are not amicable to this type of treatment. For such claims, a different approach is needed.

Although we are discussing empirical modalities, the actualist-manipulationist approach is not fully a posteriori, except when dealing with actualized possibilities and contingencies. Some kind of ampliative inference, either inductive or abductive, is required when making generalizations or using manipulations to gain new modal knowledge. The ampliative inferences add a non-empirical component to this approach. Hence, even though the account is largely empirical or a posteriori, it is not without an a priori or rationalistic component—albeit a minor one.

Finally, the ampliative inferences that the actualist-manipulationist view rests on can be *pre-theoretical*. That is, they do not require any prior theory but can simply be a matter of ‘pure’ empirical observations. Of course, there are popular claims that *all* our observations are theory-laden<sup>14</sup> but, for our purposes, it is sufficient that pre-theoretical thinking is possible, not that it is, in fact, common. Let us note that, given our evolutionary origins, there must have been a time when there were no scientific theories, even if simply for the fact that there was no language.

#### 4 Relative modality and inference-making

Another way of making inferences about modalities is based on relative modality (RM) (cf. Quine, 1982, p. 121; Melia, 2003, pp. 15–18; Girle, 2003, pp. 96–97). The conception of relative modality is an old one, but curiously enough, it is given very little attention in the current literature on modalities.<sup>15</sup> However, many theories on the epistemology of modality are implicitly based on it (see, e.g., Williamson, 2007; Bueno & Shalkowski, 2015; Fischer, 2016, 2017; Pättiniemi et al., forthcoming), making its proper explication even more important. In addition, the different varieties of modality—such as logical, metaphysical, epistemic, natural—presuppose RM even though the term “relative modality” is seldom used (see, e.g., Vaidya, 2015; Kment, 2021b). Also, in the context of the philosophy of physics Maudlin (2020) uses an approach to modalities that can be seen as a special case of relative modality.<sup>16</sup>

The idea behind relative modality is a simple one: modal statements are evaluated in relation to a system, such as a model or a theory. We then say that given a system *S* a statement *X* is.

- (1) possible, iff affirming *X* does not lead to a contradiction within *S*,
- (2) necessary, iff affirming not-*X* leads to a contradiction within *S*,
- (3) impossible, iff affirming *X* leads to a contradiction within *S*, and
- (4) contingent, iff neither affirming *X* nor not-*X* leads to a contradiction within *S*.

<sup>14</sup> For a paradigmatic version of the argument, see Kuhn (1962, pp. 111–123).

<sup>15</sup> For example, the *Internet Encyclopedia of Philosophy* does not even mention the term and both the *Stanford Encyclopedia of Philosophy* and Joseph Melia’s monograph, published as part of Acumen’s *Central Problems of Philosophy*, only mentions it in passing (Melia, 2003, pp. 15–18).

<sup>16</sup> We thank an anonymous reviewer for bringing this to our attention.

Relative modal statements can be seen as a priori, since their truth-values depend only on the system chosen and not on what the real world is like. Of course, the reason why we are dealing with a given system might be that we have a posteriori found it to be a good one in modelling certain aspects of the world. But it has no bearing on the relative modalities of the system whether or not this is so.

Roughly, a system can be characterized as *what is kept fixed* (see, e.g., Quine, 1982; Williamson, 2007). Quine, for instance, has remarked on the connection between necessity and fixedness as follows:

Relative to a particular inquiry, some predicates may play a more basic role than others, or may apply more fixedly; and these may be treated as essential. [...] [T]he very notion of necessity makes sense to me only relative to context. Typically it is applied to what is assumed in an inquiry, as against what has yet to transpire. (Quine, 1982, p. 121.)

Something is fixed if we accept it as an unchanging part of our present inquiry. Although Quine's wording seems to imply that he is considering empirical inquiry, his point can be extended to more rationalistic endeavors.<sup>17</sup>

One example of a modally apt system is provided by the game of chess. The rules of chess mark out which moves are *in principle* possible, contingent, necessary, or impossible (i.e., according to the rules). The state of play—the specific position of the pieces—determines which of those moves are *in practice* possible, contingent, necessary, or impossible. A system might be one where we keep just the rules of chess fixed or the one where we keep both the rules and the state of play fixed. As an easy example, it is impossible to start a game of chess by moving the queen. This is because the queen cannot move through or over the other pieces like a knight can.

The rules of chess, and games in general, are not an empirical matter pertaining to natural modalities. They are not based on empirical discoveries, except perhaps findings about what kinds of games human beings have an interest in playing. This again demonstrates that relative modality is only indirectly empirical, if empirical at all. Of course, someone who does not know the rules can learn them by following a number of chess games or trying to play against a more knowledgeable opponent, like a computer. However, this would fall under actualist-manipulationist modal inferences, even if on its basis, one would formulate a theory of the game's relative modalities.

Bob Fischer's "theory-based modal epistemology" (Fischer, 2016, 2017) comes close to our conception of RM. In Fischer's view, one is justified in believing a modal claim if one believes the claim based on a theory, according to which the claim is true, and one is justified in believing the theory (Fischer, 2017, p. 17). Despite the similarities with our and Fischer's positions, he makes several additional assumptions, including the requirement of mind-independent scientific realism (Fischer, 2016, 2017, pp. 5–6), which we consider unnecessary. Our view of RM would, in principle, be acceptable both to him and to an empiricist, like Bueno or van Fraassen. Fischer also states that imprecise and non-explicit mental models are sufficient for justifying modal claims (Fischer, 2016, 2017, pp. 25–27). We, in contrast, insist that a justified modal inference has to be *explicated*: one needs to argue that affirming something within some system

<sup>17</sup> It is also good to note that Quine rejects absolute or objective necessity (see, e.g., Quine, 1966). Divers (2018) offers some discussion and references.

does or does not cause a contradiction in it.<sup>18</sup> After all, our beliefs concerning systems, like theories or games, and their implications can be mistaken.

In contrast to chess, a scientific model or theory is based on empirical research. As an example, the special theory of relativity is derived from empirical findings in addition to formal considerations. It can be used to determine the impossibility of superluminal travel within the system.<sup>19</sup> By adding background assumptions (initial conditions, etc.), predictions about more specific situations can be derived from scientific models or theories.<sup>20</sup> This is analogical with keeping a certain state of play fixed in chess. So, from the general theory of relativity, one can calculate the possible trajectories of a comet, given its initial state. The number of possible trajectories will depend on how little the initial conditions are allowed to vary.

Maudlin's (2020) view of physical modalities is very much in line with the preceding paragraph, though limited to physical theories, or rather "laws", which he takes to be "[t]he fundamental concept in contemporary physics" (Maudlin, 2020, p. 524). Maudlin thinks, as do we, that given the equations of physics, we can almost trivially make modal inferences through varying boundary conditions, initial values, and so on. As he states, "[a]ll one does is treat the set of mathematical models of the basic dynamical equations as the 'possible worlds' in standard modal semantics" (Maudlin, 2020, p. 525). There are, however, important differences between our RM and Maudlin's view. First, RM can be used *whenever* we have a system to base it on, not only in physics. Second, we need not, as Maudlin does (Maudlin, 2020, p. 523, 528), commit to *any* ontology of a system under study: we see no need to take "laws" as a "fundamental concept" in order to make modal inferences.

Getting back on track, let us take a more substantial example from modern physics. An important result in the foundations of quantum mechanics is a purely formal result dealing with the *structure* of quantum mechanics: the Kochen–Specker theorem (Kochen & Specker, 1967). The theorem starts with two premises which can be characterized in the following way.<sup>21</sup> The first premise states that the statistical properties of quantum mechanics have to be replicated. The second premise states that all observables in the theory can be assigned definite values without any reference

<sup>18</sup> Due to Gödel's incompleteness theorem, it is, of course, a known fact that sufficiently strong formal systems cannot prove all of their truths. However, whether we are talking about semantic or syntactic consequence, we take it that these depend on the features of the system and logic in question and not on, say, the intuitions of human investigators. Specifying the system carefully is thus extremely important. Besides providing enriched inferential tools, one purpose of RM is to represent modal information that is publicly evaluable. Some statements in RM may also remain undetermined, but this is not a feature unique to modalities.

<sup>19</sup> The mathematics of special relativity alone cannot establish this. One needs to add further constraints to keep the results 'physical'. One such requirement is for all magnitudes to have values that are real numbers.

<sup>20</sup> This does not seem to suffice for Fischer (2016, 2017, p. 22). According to him, an epistemology of modality is insufficient if it merely grants us the ability to make empirical predictions. As a realist, he thinks that explanations are also required and, in order to explain, a theory needs to be true in some deep metaphysical sense. Our view does not make such prerequisites, and, following Woodward (2003, pp. 10–12), we think that prediction and explanation are often (though not always) different sides of the same coin.

<sup>21</sup> We avoid the technicalities of the proof, as they are both rather tedious and unnecessary for the point being made here.

to a measurement context. That is, all the properties of a quantum object<sup>22</sup> will have well-defined values in all contexts. These two premises taken together lead to a contradiction, as shown by Kochen and Specker (1967) among others (see, e.g., Peres, 1991; Kernaghan, 1994; Cabello et al., 1996). The first premise might seem trivial, but it gives the theorem its bite; it makes clear that the theorem restricts *any* theory that aims to replicate the empirical structure of quantum mechanics. So, the upshot of the theorem is that any ‘hidden-variable’ replacement for quantum mechanics “which would attribute a definite result to each quantum measurement, and still reproduce the statistical properties of quantum theory, must necessarily be *contextual*” (Peres, 1991, p. L175). Thus, here we have an inference to a *necessity* in quantum mechanics. But what does ‘contextual’ mean in this context? In short, it means that for any three operators (corresponding to observables of a quantum object)  $A$ ,  $B$  and  $C$  such that  $[A, B] = [A, C] = 0$ , and  $[B, C] \neq 0$ , the result of the measurement of  $A$  depends on whether  $A$  is measured alone or together with either  $B$  or  $C$  (Peres, 1991, p. L175). So, it is only possible to assign determinate values to observables if a measurement context is also provided. This gives a powerful constraint on the space of possibilities in quantum theories. Of note here is that *both* the inference of a necessity as well a possibility in the context of science—theoretical physics in this instance—is conditional on the system used.

Things are not always as apt for formal treatment as in the case of chess or physics. However, this does not mean that RM would be irrelevant in these cases. Indeed, it might still be our best way to make modal inferences, as manipulations might sometimes be out of the question. Let us consider two historical claims as examples:

- (1) Napoleon could have won at Waterloo, and, therefore, it is contingent that he lost.
- (2) The use of nuclear weapons was impossible during the Battle of Waterloo.

Both of these seem quite plausible, but let us try to flesh out how to deal with them using RM. In order to justify the claim that Napoleon’s loss at Waterloo was contingent, we need to allow at least some counterfactuals. For if we keep *everything* fixed, the end result would also be fixed, which implies that Napoleon’s defeat was necessary after all.<sup>23</sup> So, one might argue, relative to a system where the number of troops, weather conditions, and so on are kept fixed, but allowing for Napoleon having anticipated for Blücher’s actions better, commencing the battle earlier, and instructing marshal Grouchy more effectively, and so on he could have won the battle (Schom, 1992, pp. 266–267).

For the second claim—the use of nuclear weapons was not possible during the Battle of Waterloo (in 1815)—what is kept fixed is again what matters. One would need to allow for the discovery of pure uranium to have happened several decades before it did (uranium was discovered in 1789 but isolated for the first time in 1841), for the discovery of radioactivity (actually discovered by Becquerell in 1896) and the special theory of relativity (discovered by Einstein in 1905) almost a century before, and not to mention quantum mechanical atomic theory over a century before

<sup>22</sup> Here the word “system” would be better, but we opt for “object” in order not to cause confusion with the system(s) used in RM.

<sup>23</sup> This is exactly what a necessitarianist would do. Indeed, necessitarianism can be understood through RM as the metaphysical position that keeps all past, present, and future states fixed.

(the Rutherford–Bohr model for the hydrogen atom is from 1913, but a more final quantum theory is that due to Schrödinger and Heisenberg is from 1925), and in addition huge advancements in material technology, instrumentation, and so on would have needed to happen much earlier. Historians are usually not willing to make such drastic counterfactual changes to history. The alterations required to make Napoleon’s loss contingent are considerably lesser than those required for the use of nuclear weaponry at the same battle. In fact, it is quite difficult to say what historical facts could be kept fixed if one allows the use of atomic bombs at 19th-century battles as a possibility.

From the two examples of Napoleon’s possible victory at Waterloo and the possible trajectories of a comet, we can see how *counterfactuals* can be evaluated in RM. A comet has, as a matter of fact, a single well-defined trajectory. But the general theory of relativity allows for other trajectories if we allow the initial conditions to vary. Building on this, we can now make the counterfactual statement  $C$ : “given the velocity  $v$  of the comet  $X$ , had its angle of entry to our solar system been  $\theta'$ , instead of  $\theta$ ,  $X$  would have hit the Earth”. So, our system  $S_C$  is now: general relativity + initial conditions of the actual case, *except*  $\theta'$  is swapped for  $\theta$ . How is one to determine if  $C$  is true or not? We do the appropriate calculation and find out whether  $X$  hits the Earth in  $S_C$  or does not. If it does, then  $C$  is true. If not, then  $C$  is false. So, we have a way of evaluating counterfactuals relative to a system.<sup>24</sup>

Williamson’s epistemology of modality is based on our ability to evaluate counterfactual conditionals while keeping some “constitutive facts” fixed (Williamson, 2007, p. 164, 170). Despite his emphasis on counterfactuals, in practice, Williamson’s theory is based on relative modality with an absolutist twist: some things should always be kept fixed. However, Williamson does not inform his reader how one can know which facts or matters are to be taken as constitutive and why (Fischer, 2016; Roca-Royes, 2011). In our view, there is no need to talk about constitutivity. What should be fixed depends on the purpose of the system. RM has the benefit that it enables us to represent the division between different modal spheres as simply concerning what we decide to keep fixed in our systems at a given time. Natural modalities, for instance, encompass modalities that have been fixed employing the actuality-to-possibility principle, manipulations, and the relative modalities of our scientific systems. Metaphysical modalities concern relative modalities in metaphysical systems.<sup>25,26</sup> Logical modalities concern the relative modalities in a system of logic that we have chosen based on the axioms of that logic. Finally, epistemic modalities concern that which can and cannot be ruled out from our or some other epistemic situation or point of view.

<sup>24</sup> The case with Napoleon will be trickier to figure out in practice, and any answer given will probably be subject to controversy. Nevertheless, the same principle can be applied.

<sup>25</sup> Clarke-Doane (2019) seems to be in agreement with us that metaphysical modality is not absolute, but rather than going the strict RM route, he takes “possibility” and “necessity” to fall under several differing conceptions, none of which are more absolute than the others.

<sup>26</sup> According to our relative modality account, metaphysical modalities are determined by what is fixed in a metaphysical system. Leech (2011) argues that metaphysical necessity can be cashed out through relative modality. Although we are not ready to accept Leech’s program as a whole, we think that it shows promise. Fischer (2016) also hints at a similar approach.

One might worry whether we are implicitly giving logic a fundamental status. Given our way of evaluating modal statements presented at the beginning of this section, which rests on contradictions and negations, do we not have to specify a logic and stick to it? Simply put: no, we need not. Classical logic with contradiction and negation simply gives us a convenient metalanguage to talk about various systems with modal operations, and we will only be committed to a given logic insofar as it suits us in achieving whatever goals we may have. So, it is true that a logic is needed, but we may choose to use whichever logic we find convenient for a given task. Hence, the choice of which logic to use—to the extent that we are actually at all able to choose between logics—is in our view a pragmatic one. Of course, one must always start with some system of inference, but we see no reason why some of its rules could not be relaxed and new ones fixed gradually. For example, because intuitionistic logic does not have a duality between the quantifiers  $\forall$  and  $\exists$ , its resulting modal extension means losing duality between the modal operators  $\Box$  and  $\Diamond$ .

A particularly interesting challenge to our view might be offered by dialetheism, which states there are true *dialetheias*, true contradictions. Now certainly, if some contradictions are true, then they also have to be possible. This flies right at the face of our relative definition of possibility, based on the Aristotelian Law of Non-Contradiction. As Bueno and Shalkowski (2015, p. 682) note, modal operators ultimately depend on the consequence relation of the assumed background logic. As there are different ways to construct logics that wind up having different kinds of consequence relations, one cannot define modal operators simpliciter, but only in relation to a system of logic. This is totally fine and in line with our account of RM. It is simply a case of higher-order relativity, where the interpretations of the rules for the modal operators themselves are also newly relativized.

Thus, in the case of radically different kinds of logics, like paraconsistent logic, there might be a need to reconsider how the basic modal operations are understood. In these kinds of situations, however, it might also be questioned whether we are talking about the same notion of possibility anymore. If negation does not behave like negation, is it really negation? The same can be asked in the context of modal operators. Ultimately, however, for our purposes, it is enough that the resulting system is not formally trivial and that the newly defined modalities bear some inferential relationship to the system features.<sup>27</sup> However, to keep the connection to a common subject matter and especially the scientific practice of making modal inferences, we employ the heuristic of sticking to a reasonable family resemblance between our metalanguage and modalities as they are typically conceived in natural languages. Unlike modalists, such as Bueno and Shalkowski (2015), we do not need to take any notion of modality as primitive, save for this pragmatic usage of modal terms in ordinary and scientific discourse.

<sup>27</sup> Given an arbitrary logic  $L$  and a system  $S$ , we could define  $\Diamond A$  as such that the assertion of  $A$  in  $S$  does not *trivialize*  $S$  (i.e., does not  $L$ -entail its every state or well-formed formula). In the case of necessities of the form  $\Box A$ , in turn,  $A$  could be a fixed assumption of  $S$  or an  $L$ -truth, etc. Bueno and Shalkowski (2015) seem to be sympathetic to this kind of treatment of relative modalities.

## 5 The relationship between the two epistemologies

We have presented two epistemologies for justifying modal inferences, actualist-manipulationist (AM) and relative modality (RM). The obvious question then is: how, if at all, are these two ways related to each other? Recall that AM is mainly a posteriori and RM is mainly a priori. Let us try to bridge the gap from both sides. On the one hand, starting with pre-theoretical ampliative inferences, we can begin to build *theories* that explain our generalizations. These theories, in turn, can be thought of as systems in the sense of RM. So, we build an empirically adequate model of a situation and then try to figure out its modal structure using relative modalities.

On the other hand, we can start with a system and use it to model a given phenomenon. Then we can derive from the system modal claims concerning the phenomenon and see whether they match up with our empirical findings. A system that has been found adequate can then be used as a basis for ampliative generalizations in the AM way. Moreover, the modal claims inferred from a system can be empirically tested by using the AM methodology, like experiments, interventions, and even chemical or biological synthesis (for an example of the latter, see Koskinen, 2017). In a word, we can use both approaches to study the same modal phenomena in the world.

It is very rarely the case these days that we start from a purely pre-theoretical position. Our ampliative inferences rest on all sorts of theories about the way things are and behave. These theories might be folk theories, philosophical theories, theological theories, or scientific theories, and they may or may not be reliable. Whatever the case, they shape the way we form our inductive generalizations by shaping what kinds of manipulations we take to be feasible and what types of similarities we find relevant. Here, however, we will focus our attention on scientific theories.

The progress of science has given us a plethora of reliable ways for making good inductive generalizations. For instance, if we know the number of valence electrons a chemical element has, we can predict its chemical properties and vice versa. Many if not all of these properties will be modal properties: such as the possibility (or impossibility) of forming covalent bonds. This example from chemistry illustrates that we are dealing here with a mixed model of modalities—when reasoning from the number of valence electrons to chemical properties, we are using RM, and when reasoning from chemical properties to the number of valence electrons, we are making an inductive inference, informed by theory, from our empirical observations. More generally: We make *predictions* about modal properties of empirical reality based on our theories and relative modality. We also make inferences about the modal properties of empirical reality by making *observations* and *manipulations*. In addition, we build and correct our theories based on their results. This interplay between RM and AM grants us most of our current modal knowledge—if not, indeed, our scientific knowledge *in general*.

One might be inclined to think that AM *merely* enables us to fix things in our systems, and, fair enough, this is an important way in which AM inferences are used. However, this is true only when we are dealing with impossibilities and necessities, that is, when no manipulation can alter or actualize something. But when AM informs us about a possibility or a contingency, it does not guide us on what should be fixed in a given system. It only states that if a system aims to describe natural modalities, it

should be such that the descriptions of actualized states do not cause a contradiction in it.

Another way how RM and AM inferences are connected is that counterfactual claims, which are derivable from a system, can be tested by manipulations—given that the system in question aims to describe empirical matters. Take a simple example. A system  $S$  aims to describe under which circumstances objects fall over, and the following counterfactual claim can be derived from the system: “If an object’s center of mass moves outside of its support, then the object in question will fall over.” Now, we set out to test the claim. We do this by taking an object and manipulating it so that its center of mass moves outside of its support. If the object falls over, we can infer that  $S$  is an adequate model for the phenomenon in question. So, more generally, one looks for the counterfactual claims derivable from a system and then seeks to do manipulations in order to show whether or not these counterfactuals turn out to be empirically supported. Here, the counterfactuals derived from a system can be seen as *predictions* that then are tested through manipulations, or even by observations—in cases where the world is kind enough to supply a change of situations for us.

Moreover, counterfactual claims that have been established through manipulations trivially contain some modal information that can be used in constructing systems with empirical targets. In order to empirically justify a counterfactual, say, “If  $A$  would happen, then  $B$  would happen,” one would have to actualize  $A$  and see if  $B$  occurs. If the manipulation is successful and produces the expected result, then any system that fulfills the following criteria can adequately model the counterfactual in question:

- (1)  $A$  and  $B$  do not contradict each other,
- (2)  $B$  is not trivially true in the system, and
- (3) if  $A$  is fixed in the system, then also  $B$  is true in it.

The above considerations shed some light on the interplay between the two ways of making modal inferences. So, on the one hand, we build systems to model empirical phenomena and look at whether the modal inferences derived from the systems hold empirically. On the other hand, we make observations and manipulations (and ampliative generalizations) about different phenomena and use them to build theoretical systems that model these phenomena.

Let us take one more example from science, this time from crystallography. Before the discovery of “quasicrystals” in 1982 (Shechtman et al., 1984), the received wisdom was that only certain types of point symmetries are possible in crystals. Indeed, the old view of crystals was that they are composed of a regularly repeating array of atoms. But another characteristic feature of crystals is that they exhibit a sharp (electron) diffraction pattern. It was this diffraction pattern that was thought to be possible only for a regularly repeating array of atoms, but the crystals found by Shechtman, Blech, Gratias, and Cahn had a more complex point symmetry than that of traditional crystals, one that did not compose of a regularly repeating pattern, but a rather more complex symmetry of the icosahedral group  $m\bar{3}5$ . So, here a theoretical impossibility was shown to be false by empirical means—an inference of possibility from actuality. But, naturally, the initial theoretical claim had been derived from a theory supported and inspired by empirical work on crystals.

Each and every modal claim derived from a given system can also be used as a falsifier for that system if the system aims to describe the observable world. For instance, according to the special theory of relativity, superluminal signaling is impossible. But if someone were able to transmit information at a velocity that exceeds the speed of light, this would seriously question the validity of the system, namely the special theory of relativity.<sup>28</sup>

## 6 Conclusions

We have presented in this paper a two-pronged epistemology of modal inferences, one based on an actualist-manipulationist (AM) method and the other on relative modality (RM). We argued that these methods can accommodate our scientific inferences, especially when used in combination.

These routes of making modal inferences are neutral with respect to metaphysical accounts on why the claims in question are correct—be it due to essences or some other metaphysical foundation. Hence, if there are several competing metaphysical explanations for an empirically discovered modal fact, these methods support all of them equally. In other words, the methods are unable to pick out, nor do they require the correct metaphysical account, even if there is one. Indeed, the metaphysical ground of modality remains totally untouched, and we are even willing to go as far as to declare that any additional metaphysics is not needed for making empirically-based modal claims. Despite this, it seems to give us modal knowledge, though it clearly is fallible.

We think one of the strengths of our account is that it does not draw a deep division between modal and non-modal aspects of scientific reasoning. As our examples demonstrate, scientific inferences typically are modal inferences. We often start from what is actual and work our way from there toward modal facts. However, sometimes the converse is the case. We might have scientifically justified knowledge about what is possible or necessary without having a clear picture of the actual situation or an infallible grasp of an underlying, fundamental metaphysical truth. Depending on the situation, modal inferences can be tools to learn new things about what is actual, or the conclusion of modal inference can be the goal of inquiry by itself. The two epistemologies presented in this paper are designed to account for both of these roles.

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<sup>28</sup> Of course, as the Duhem-Quine thesis informs us, we can always opt to let something other than the system go, so it is not automatically the case that evidence of superluminal signaling would force us to abandon the special theory of relativity.

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## Declarations

**Conflict of interest** All authors declare that they have no conflicts of interest.

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## References

- Armstrong, D. (2010). *Sketch for a systematic metaphysics*. Oxford University Press.
- Arseculeratne, S. N., & Arseculeratne, G. (2017). A re-appraisal of the conventional history of antibiosis and Penicillin. *Mycoses*, *60*(5), 343–347.
- Berto, F. (2017). Impossible worlds and the logic of imagination. *Erkenntnis*, *82*, 1277–1297.
- Bueno, O., & Shalkowski, S. A. (2015). Modalism and theoretical virtues: Toward an epistemology of modality. *Philosophical Studies*, *172*(3), 671–689.
- Cabello, A., Estebarez, J. M., & García-Alcaine, G. (1996). Bell-Kochen-Specker theorem: A proof with 18 vectors. *Physics Letters A*, *212*, 183–187.
- Chalmers, D. (2002). Does conceivability entail possibility? In T. Gendler & J. Hawthorne (Eds.), *Conceivability and possibility* (pp. 145–201). Oxford University Press.
- Chalmers, D. (2010). *The character of consciousness*. Oxford University Press.
- Clarke-Doane, J. (2019). Modal objectivity. *Noûs*, *53*(2), 266–295.
- Dennett, D. (1984). *Elbow room: The varieties of free will worth wanting*. MIT Press.
- Divers, J. (2002). *Possible worlds*. Routledge.
- Divers, J. (2018). W(h)ither metaphysical necessity? *Aristotelian Society Supplementary*, *92*(1), 1–25.
- Fischer, B. (2016). A theory-based epistemology of modality. *Canadian Journal of Philosophy*, *46*(2), 228–247.
- Fischer, B. (2017). *Modal justification via theories*. Springer.
- Fischer, B., & Leon, F. (Eds.). (2017). *Modal epistemology after rationalism*. Springer.
- Girle, R. (2003). *Possible worlds*. Acumen.
- Grüne-Yanoff, T. (2013). Appraising models nonrepresentationally. *Philosophy of Science*, *80*, 850–861.
- Hale, B. (2013). *Necessary beings: An essay on ontology, modality, and the relations between them*. Oxford University Press.
- Hanrahan, R. (2017). The actual and the possible. *Journal of Philosophical Research*, *42*, 223–242.
- Hawke, P. (2011). Van Inwagen's modal skepticism. *Philosophical Studies*, *153*, 351–364.
- Houbraken, J., Frisvad, J. C., & Samson, R. A. (2011). Fleming's penicillin producing strain is not *Penicillium chrysogenum* but *P. rubens*. *IMA Fungus*, *2*(1), 87–95.
- Ichikawa, J., & Jarvis, B. (2012). Rational imagination and modal knowledge. *Noûs*, *46*, 127–158.
- Kment, B. (2021a). Essence and modal knowledge. *Synthese*, *198*, 1957–1979.
- Kment, B. (2021b). Varieties of Modality. In E. N. Zalta (Ed.) *The Stanford Encyclopedia of Philosophy* (Spring 2021 Edition). <https://plato.stanford.edu/archives/spr2021/entries/modality-varieties/>
- Kernaghan, M. (1994). Bell-Kochen-Specker theorem for 20 vectors. *Journal of Physics A: Mathematical and General*, *27*, L829.
- Kochen, S., & Specker, E. P. (1967). The problem of hidden variables in quantum mechanics. *Journal of Mathematics and Mechanics*, *17*, 59–87.

- Koskinen, R. (2017). Synthetic biology and the search for alternative genetic systems: Taking how-possibly models seriously. *European Journal for Philosophy of Science*, 7(3), 493–506.
- Kuhn, T. S. (1962). *The structure of scientific revolutions*. University of Chicago Press.
- Kung, P. (2010). Imagining as a guide to possibility. *Philosophy and Phenomenological Research*, 81, 620–663.
- Ladyman, J., & Ross, D. (2007). *Every thing must go*. Oxford University Press.
- Latham, N. (2011). Are fundamental laws necessary or contingent? In J. K. Campbell, M. O'Rourke, & M. Slater (Eds.), *Carving nature at its joints: Natural kinds in metaphysics and science* (pp. 97–112). MIT Press.
- Leech, J. F. (2011). *The Varieties of Modality: Kantian Prospects for a Relativist Account*. Academic Dissertation, University of Geneva and the University of Sheffield.
- Leon, F. (2017). From modal skepticism to modal empiricism. In B. Fischer & F. Leon (Eds.), *Modal epistemology after rationalism* (pp. 247–261). Springer.
- Lewis, D. (1986). *On the plurality of worlds*. Blackwell Publishers.
- Lin, M. (2012). Rationalism and necessitarianism. *Noûs*, 6(3), 418–448.
- Lowe, E. J. (2012). What is the source of our knowledge of modal truths. *Mind*, 121(484), 919–950.
- Mallozzi, A. (2021a). Putting modal metaphysics first. *Synthese*, 198, S1937–S1956.
- Mallozzi, A. (2021b). Special issue of *synthese* on new directions in the epistemology of modality: Introduction. *Synthese*, 198, 1841–1859.
- Marshall, M. (2008). 10 impossibilities conquered by science. *NewScientist*. Retrieved from 6 February 2021. <https://www.newscientist.com/article/dn13556-10-impossibilities-conquered-by-science/>
- Massimi, M. (2019). Two kinds of exploratory models. *Philosophy of Science*, 86(5), 869–881.
- Maudlin, T. (2007). *The metaphysics within physics*. Oxford University Press.
- Maudlin, T. (2020). A modal free lunch. *Foundations of Physics*, 50, 522–529.
- Melia, J. (2003). *Modality*. Acumen.
- Pearl, J. (2009). *Causality: Models, reasoning, and inference* (2nd ed.). Cambridge University Press.
- Peres, A. (1991). Two simple proofs of the Kochen-Specker theorem. *Journal of Physics A: Mathematical and General*, 24, L175–L178.
- Priest, G. (2021). Metaphysical necessity: A skeptical perspective. *Synthese*, 198, 1873–1885.
- Psillos, S. (2009). *Knowing the structure of nature: Essays on realism and explanation*. Palgrave Macmillan.
- Pättiniemi, I., Koskinen, R. & Hirvonen, I. (Forthcoming.) Epistemology of modality: Between the rock and the hard place. *Acta Philosophica Fennica*.
- Quine, W. V. O. (1966). Three grades of modal involvement. *The ways of paradox and other essays* (pp. 156–174). Harvard University Press.
- Quine, W. V. O. (1982). *Theories and things*. Belknap Press.
- Roca-Royes, S. (2011). Modal knowledge and counterfactual knowledge. *Logique Et Analyse*, 54(216), 537–552.
- Roca-Royes, S. (2017). Similarity and possibility: An epistemology of de re possibility for concrete entities. In B. Fischer & F. Leon (Eds.), *Modal epistemology after rationalism* (pp. 221–245). Springer.
- Schom, A. (1992). *One hundred days: Napoleon's Road to Waterloo*. Oxford University Press.
- Shechtman, D., Blech, I., Gratias, D., & Cahn, J. W. (1984). Metallic phase with long-range orientational order and no translational symmetry. *Physical Review Letters*, 53(20), 1951–1953.
- Shoemaker, S. (1998). Causal and metaphysical necessity. *Pacific Philosophical Quarterly*, 79(1), 59–77.
- Tahko, T. E. (2017). Empirically-informed modal rationalism. In B. Fischer & F. Leon (Eds.), *Modal epistemology after rationalism* (pp. 29–45). Springer.
- Thomasson, A. L. (2021). How can we come to know metaphysical modal truths? *Synthese*, 198, 2077–2106.
- Toby, S. (2000). Acid test finally wiped out vitalism, and yet.... *Nature*, 408, 767.
- Vaidya, A. (2015). The epistemology of modality. In E. N. Zalta (Ed.) *The Stanford Encyclopedia of Philosophy* (Summer 2015 Edition). <https://plato.stanford.edu/archives/win2017/entries/modality-epistemology/>
- Verreault-Julien, P. (2019). How could models possibly provide how-possibly explanations? *Studies in History and Philosophy of Science*, 73, 22–33.
- Vetter, B. (2015). *Potentiality: From dispositions to modality*. Oxford University Press.
- Vetter, B. (2020). Perceiving potentiality: A metaphysics for affordances. *Topoi*, 39, 1177–1191.
- van Inwagen, P. (1998). Modal epistemology. *Philosophical Studies*, 92(1), 67–84.
- Wang, J. (2021). The epistemological objection to modal primitivism. *Synthese*, 198, 1887–1898.

- Williamson, T. (2007). Knowledge of metaphysical modality. *The philosophy of philosophy* (pp. 134–178). Blackwell.
- Williamson, T. (2016). Modal science. *Canadian Journal of Philosophy*, 46(4–5), 453–492.
- Williamson, T. (2017). Modality as a subject for science. *Res Philosophica*, 94(3), 415–436.
- Woodward, J. (2003). *Making things happen: A theory of causal explanation*. Oxford University Press.
- Wöhler, F. (1828). Ueber künstliche Bildung des Harnstoffs. *Annalen Der Physik*, 88, 253–256.
- Yablo, S. (1993). Is conceivability a guide to possibility? *Philosophy and Phenomenological Research*, 53(1), 1–42.

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