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Causation and Realism: The Role of Instrumentally Mediated Empirical Evidence

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In remembrance of Ian Hacking (1936–2023)

Abstract: This chapter explores the relevance of empirical evidence to real causes. I argue for the claim that instrumentally mediated empirical results are causally dependent on unobservable entities. I develop this idea in the context of discussions on entity realism. As a consequence of my argument, an antirealist version of empiricism, which underlines the significance of empirical evidence but which abstains from real causation, is incoherent.

Keywords: Real Causes, Scientific Instruments, Empirical Evidence, Entity Realism, Empiricism

1 Introduction

This chapter concerns the intersection of causation and scientific realism. It asks the question of whether instrumentally mediated empirical evidence is causally dependent on unobservable entities such as protons, genes, and black holes, which cannot be perceived using our bodily senses. In this regard, the role of scientific instruments is prominent since the very definition of unobservable entities reflects the use of scientific instruments. Observable objects such as tables and trees can be perceived using our bodily senses. Unobservable subatomic particles or astrophysical objects, on the other hand, cannot be perceived in this way. Scientific instruments such as microscopes, telescopes, and interferometers are necessary to detect/measure the properties and behaviors of these entities. For this reason, one cannot discuss scientific measurement and metrics without considering the role of instruments in science. In this chapter, I focus on a specific aspect of this role: the causal connection between the empirical results obtained by measuring/detecting instruments and unobservable entities. My discussion is relevant to the 'epistemological' question of causality insofar as it explores our *justification* for beliefs in unobservable entities, as the causes of instrumentally mediated empirical evidence. It is also relevant to the metaphysical question of causality insofar as these beliefs are held about the *existence* of unobservable entities.[1] Furthermore, because I discuss the nature of *causal*

[1] The metaphysical study of unobservable entities is constructed based on *justified* beliefs, so in this sense epistemology is prior to metaphysics. This priority agrees with the epistemology-*first* approach of Massimi (2022, pp. 15 and 330) and Russo (2022, chapter 10); see also Khalili (2023b, p. 15).

explanations, as well as the *inference* of unobservable entities from empirical evidence, this chapter is concerned with these problems of causality: explanation and inference (on various questions and problems of causality, see Illari and Russo 2014).

My discussion of the connection between unobservable entities and instrumentally mediated evidence takes place in the context of the scientific realism debate, which revolves around the nature of unobservable entities. In this debate, realists generally hold a positive attitude toward the existence of these entities, but antirealists contend that there is insufficient justification to consider them to be real. I develop my answer to the main question of the chapter particularly within the framework of a subset of realism: entity or experimental realism. I use 'entity realism' and 'experimental realism' interchangeably. 'Experimental realism' highlights the fact that scientific *methodology* heavily relies on experimentation, while 'entity realism' underscores the *epistemological* dimension of the same thesis: the trustworthy knowledge gained from experimentation concerns the existence of entities. Entity realism holds particular significance for this chapter since it illuminates how what we think is real depends on causality and also on how we use instruments and what we can measure. Notably, the attractiveness of entity realism lies in its exploration of the implications of experimental detection/measurement for our epistemology of unobservable entities. Accordingly, entity realism renders what we can detect/measure pivotal to the realism debate, and thus it is especially suitable for my discussion of instrumentally mediated evidence, obtained as a result of detection/measurement practices.

The central question of the chapter about the connection between empirical evidence and unobservable entities is clearly related to the topic of measurement/detection. Empirical evidence is prepared as a result of the detection/measurement that scientific instruments carry out. Additionally, as section 2 will elaborate, a remarkable insight of entity realism concerns the fact that experimenters actively develop independent ways of detecting/measuring entities, which assures the scientific community that the detected entity is supported by 'robust' evidence. Thanks to the importance of the concept of 'robustness' to entity realism, my discussion of empirical evidence is intimately related to the issue of measurement/detection. What is more, as section 3 will explicate based on entity realism, the quality of being empirical is characterized by a causal relation that connects the result of detection/measurement practice to the object of inquiry. This characterization of empirical evidence further relates the content of this chapter with the topic of measurement/detection.

The structure of the chapter is as follows. Section 2 presents an overview of entity realism and its development in recent years. In this context, the concepts of 'causal explanation' and 'causal warrant' are introduced and it is argued that if a number of criteria – namely, 'non-redundancy', 'material inference', and 'robustness' – are fulfilled, a belief in the existence of an unobservable entity is justified. That is to say, it is warranted to believe in the existence of a detectable property of a concrete entity insofar as it can act as a non-redundant cause that is materially inferred from the evidence obtained in a variety of independent ways of detection.[2] In this criterion, a detectable property is a property that can be detected/measured by scientific instruments. Instrumentally mediated empirical evidence allows scientists to know the properties of unobservable entities. Section 3 addresses empirical evidence produced by scientific instruments. I support the claim that instrumentally mediated empirical evidence is causally dependent on unobservable entities. While other entity realists may also imply this claim, the current chapter explicitly articulates and advocates for it. A novel implication of my articulation is that an antirealist version of empiricism, which highlights the significance of empirical evidence but refrains from acknowledging its real cause, is incoherent. Section 4 compares this novel claim with a recent argument for real causation on the basis of the requirements to exclude external disturbances. Although different, both views complement each other in contending that antirealist empiricism lacks coherence.

2 Experimental/Entity Realism

As certain portions of our successful theories turn out to not represent anything real, *selective* realists endeavor to establish criteria to distinguish between the representational components and non-representational aspects of scientific theories. A significant variant of selective realism is *entity* or *experimental* realism, which asserts that our beliefs in unobservable entities such as protons and genes, which result from appropriate experimental interactions with entities, warrant realist endorsement. Conversely, beliefs that rely solely on models, theories, or general laws do not merit realist commitment. In this manner, entity realists 'select' the former category of scientific beliefs while disregarding the latter. The idea of appropriate use of instruments and the development of appropriate experiments will play a central role in the argument of the chapter against antirealist empiricism.

Ian Hacking first coined the term 'entity realism'. He suggests that if one can causally manipulate an entity to intervene in other phenomena, one is justified to believe in the existence of that entity. Hacking's slogan is that when one can spray entities such as electrons, they are real (see, e.g., Hacking

[2] This criterion has been developed in Khalili (2023a), on which the next section partly draws.

1983, p. 23). In the second half of his *Representing and Intervening* (1983) he underpins this slogan. His main claim is that our knowledge of an entity's existence can survive even if the theoretical concepts that interpret the instruments or experimental results change. Hacking's argument for this claim is that experimenters can manipulate the entity under investigation to observe its effects. In his words, "entities that in principle cannot be 'observed' [by naked eyes] are regularly manipulated to produce new phenomena and to investigate other aspects of nature" (Hacking 1983, p. 262). Explicit examples of manipulable entities are those that can be used "as tools, as instruments of inquiry" (Hacking 1989, p. 578). In line with this claim, Ronald Giere (1988, chapter 5; Khalili 2023b) puts forward the example of protons, which are real because they are produced and employed as research tools in the investigation of the structure of various nuclei. Protons are as real as other tools employed in exploring the nuclear structure.

Nancy Cartwright (1983, essays 4 and 5) is also known as an entity realist. Her main contribution to entity realism concerns the important distinction she makes between theoretical and causal explanations. Theoretical explanations are based on laws, which can be explanatory without being true. Causal explanations, by contrast, cannot work without being true: "to accept the explanation is to admit the cause" (1983, p. 99). An entity can play its causal, explanatory role only if it actually exists. Accordingly, Cartwright "believe[s] in theoretical entities" (1983, p. 89; see also p. 92) whose causal roles can be established in "direct experimental testing" (1983, p. 98). The existence of protons, for instance, must be presupposed as the causes of effects that are observed in the investigation of the structure of nuclei.

The project of entity/experimental realism has been developed in recent years by Mauricio Suárez, Matthias Egg, and Markus Eronen, among others. In what follows in this section I describe part of this development by expounding on 'causal explanation', 'causal warrant', and the necessary conditions for believing in the existence of unobservable entities.

Mauricio Suárez (2008) advances Cartwright's experimental realism by proposing a useful distinction he proposes between 'causal explanations' and 'theoretical explanations that employ causal vocabulary'. Then, he supports an epistemic version of experimental realism, in which causal explanations are employed to provide justified inferences to the most likely cause of an effect. His analysis justifies belief in unobservable entities causing observable effects.

The distinction between ‘causal explanations’ and ‘theoretical explanations that employ causal vocabulary’ primarily serves to address Christopher Hitchcock’s (1992) objection that one can accept a causal explanation without committing to the reality of its presupposed causes. He illustrates this claim by giving some examples of putative causal explanations in which the causes are most certainly not real. For instance, he examines the famous two-slit experiment, in which electrons are propelled through a screen containing two slits and then detected on a subsequent screen. The pattern depicted is disrupted as soon as a measurement is conducted to determine which slit the electron passes through. Hitchcock suggests a possible explanation for this phenomenon: the detection process of the electron in either slit involves bouncing a photon off the electron. This interaction imparts momentum to the electron, influencing its trajectory and thus destroying the interference pattern. Hitchcock claims that this account appears highly explanatory, describing causal processes, but accepting the existence of such a photon-electron interaction “contradicts almost every interpretation of quantum mechanics, and as such would not be believed to be true by any but the most stubborn believer in hidden variables’ (Hitchcock 1992, p. 171). On the other hand, Suárez convincingly argues that this counterexample presents no causal explanation at all. At most, it offers a theoretical explanation. “In a causal explanation it is not the causal *story* that does the explaining but the causes themselves. … So if we don’t believe in the “causes” appealed to in the story then the explanation the story offers—if any—cannot be said to be causal” (2008, p. 151–152). Accordingly, the main difference between a causal explanation and a theoretical explanation that merely employs causal vocabulary is that the reality of the cause is an essential feature of the causal explanation, so pointing to an unreal cause indicates that the explanation cannot be causal in the first place.

In order for a causal explanation to account for an observable effect, a commitment to the existence of the cause is essential. “Since this type of explanation is only successful to the extent that the cause is real, inference to the most likely cause (IMLC) [from the observable effect] is strongly warranted”. Suárez describes “this type of warrant, which accrues from successful causal explanation, as causal warrant” (2008, p. 143–144). Note that endorsing causal warrant implies neither that causal warrant is infallible nor that theoretical warrant cannot be valid. Rather, the key idea is that causal warrant is much stronger than theoretical warrant. The force of it being basically so is that theoretical explanations are usually ‘redundant’, in the sense that they can be successful without being true. That is, alternative theoretical explanations can be proposed to successfully explain the phenomenon under inquiry (more on ‘non-redundancy’ below). On the other hand, the success of a causal explanation inevitably entails that the cause must exist. In other words, one has to question the success of the explanation itself to argue that the cause does not exist. To do so, one may still cast doubt on the theoretical description of the cause. However, when the conditions for a causally warranted belief in an unobservable cause are fulfilled, the fact that the cause must exist to bring about the observable/empirical effect is completely justified. But what are these conditions? Matthias Egg (2012, section 4) has addressed this question. In the remainder of this section I switch to discussing his explication of the necessary conditions for a causally warranted belief in (a property of) an unobservable entity. Building on the work of Cartwright and Suárez, Egg specifies the following conditions.

Condition 1: Non-Redundancy

When an explanation provides the only hypothesis that can account for the empirical evidence, the explanation is non-redundant (Egg 2014, pp. 50–53). Egg distinguishes between a strong and a weak sense of non-redundancy. The former requires that no other empirically adequate hypothesis (known or unknown) is conceivable. The latter implies that no alternative hypothesis that explains the empirical evidence is known. If met, condition 1 supports the weaker sense of non-redundancy. Egg claims that hypotheses that fulfill this condition, in addition to conditions II and III , which will be discussed presently, "are likely to be non-redundant in the strong sense" (2014, 91; 2016, 127). In other words, causal explanations are likely to be non-redundant in the strong sense, but this sense cannot be displayed directly. In practice, we can only indicate non-redundancy in the weak sense. This indication alone is of course not sufficient for an explanation to be considered as non-redundant in the strong sense, and thus to lead to a causally warranted belief in an unobservable entity. For this purpose, the following two conditions must also be met: the cause should be inferred *materially*, and it should provide the explanation of *robust* evidence.

Condition 2: Material Inference

The concept of 'material' in condition 2 implies that a concrete matter of fact, rather than an abstract theoretical law, should explain the phenomenon. Entities with 'detectable' properties, that is, with properties that can be detected by scientific instruments, may deserve realist commitment. However, 'auxiliary' properties, those attributed to entities only by theoretical models, are not trustworthy (Egg 2014, p. 57, n. 8; see also Chakravartty 2007, p. 47). Accordingly, a concrete matter of fact is a detectable property of a concrete entity.

Egg follows James Woodward in supporting a *manipulability* account of causation, according to which "for something to be a cause we must be able to say what it would be like to change or manipulate it" (Woodward 2003, p. 112). If C is a cause of E, then C can in principle be manipulated such that E is changed in turn. Thus, causal claims are tested through manipulating the presumed cause by modifying it in order to see the change in the presumed effect. Egg accordingly defines a material inference as "one that results in ascribing to a concrete entity a property for which there is a well-defined notion of what it means to modify it" (Egg 2014, p. 58). His discussion of material inference implies that a property for which there is a well-defined notion of what it means to modify it is nothing but a 'detectable' or a 'material' property, in the sense that "we can *in principle* establish some causal contact" with it (2014, 90). Accordingly, a material inference is an inference that results in ascribing to a concrete entity a detectable property.

Condition 3: Empirical Adequacy

Egg follows Van Fraassen's (1980, 16) in defending this condition: If the observable implications of an explanation are correct, then the explanation is empirically adequate (Egg 2012, section 4.3, 2014, 59–61).

In Khalili (2023a, section 6) I propose that 'robustness' should be employed instead of Egg's criterion of 'empirical adequacy' (see also Eronen 2015; Khalili 2023c). When we study the actual practice of experimenters, we understand that they do not *merely* 'save' phenomena by presupposing theories. Rather, they actively develop *different* ways of detecting, measuring, or observing these entities. Each of these independent ways should be reproducible to be reliable, but what can assure the scientific community that the detected entity is real is indeed the availability of *a number of* different ways of detecting, measuring, or observing the entity. If the evidence is gained only through a single way of detection, one may question its validity. When a number of different ways are available, however, the robust result is hardly questionable. The idea of robustness takes into account that replicating experimental detection, measurement, or observation through different processes is central to the actual practice of experimenters.[3]

[3] About 'reproducibility' and 'replicability', I follow Radder (1996, 11–26 and 78, 1984/2012, chapter 3 and 166-169). He explains that a reliable experiment or observation needs to be reproducible by the original experimenters or by other

Robustness provides a highly adequate empirical support. Highlighting robustness, instead of mere empirical adequacy, is more consistent with the initial ideas of experimental realism in Hacking's and Cartwright's work. According to Hacking's 'argument from coincidence', the experimenters' belief in an entity increases when they can investigate the entity through different mechanisms. For instance, when different microscopes—whose working is based on other mechanisms—detect the same microscopic entity, one is quite justified to believe in the entity (see Hacking 1983, p. 201; and 1985, pp. 146–147). The argument from coincidence is also made by Cartwright (1983, essay 4, section 3). Discussing Wesley Salmon's (1984) case-study of Jean Perrin's reasoning about the existence of atoms, in which thirteen different cases are presented, Cartwright emphasizes the importance of making use of different methods in inferring the same cause from its effects.

In sum, according to (a developed version of) experimental realism, it is warranted to believe in the existence of a detectable property of a concrete entity insofar as it can act as a *non-redundant* cause that is *materially inferred* from the evidence obtained in *a variety of independent ways of detection*. This summary clearly shows that experimental realism is deeply connected to questions and problems of causation, as I said in the Introduction. The next section highlights the role of instrumentation with connection to causation in the context of experimental realism.

3 Instrumentally Mediated Empirical Evidence

A detectable property of a concrete entity is understood as a property that can be detected by scientific instruments, implying that instruments play a mediating role in the detection of unobservable entities. According to the idea of 'mediation', technology plays an ineliminable role in shaping human interaction with the world. The concept of mediation helps us understand the intricate relationship between humans and technology, emphasizing that technology is not just an external tool but an active player that fundamentally influences the way we observe and engage with the world around us. This idea comes especially from Don Ihde's (1979; 1991) postphenomenology, and it has recently been developed by, for instance, Bas de Boer (2021; see also his chapter in this volume). In line with this idea, Federica Russo (2022) has also developed the stronger position that instruments together with

experimenters. Replicability implies the reproducibility of empirical results using (radically) different processes. Replicable experiments or observations are specific cases of reproducible ones.

human agents co-produce scientific knowledge. In what follows, with the general concept of 'mediation' in mind, I focus on the *causal* connection between instrumentally mediated empirical evidence and unobservable entities.

Nora Boyd (2018) has made two conceptual points about (instrumentally mediated) empirical evidence that assist me to develop my view about the connection between empirical evidence and real causes in this section. First, she employs concepts such as 'empirical results' or 'empirical evidence' instead of 'observables' or 'experience'. The former concepts are more faithful to the results gained by means of "intricate instruments and techniques prevalent in scientific research today" (2018, p. 406). Her analysis of how empirical evidence can accumulate, be merged, and constrain rival models allows us to better understand contemporary science, in which a large volume of data is gathered and analyzed to test scientific models (see also Canali and Ratti this volume).

The second, and more crucial, point she makes is that the quality of being empirical is characterized by a 'causal story' that connects the results of scientific observations, detections, and measurements to the object of inquiry:

> In the hope of replacing observations with something more suitable to science in practice, we might consider the more generic 'empirical results,' where 'results' may be understood to include observations and other sensings but also the results of technology-aided detections and measurements, and 'empirical' may be understood in contrast with 'virtual' and 'imagined' and could be cashed out by appeal to a causal story connecting the target of interest to the generation of that result. (2018, p. 404)

> it is not just anything that can play the role of an empirical result – it needs to be possible to tell a story about how the empirical result is causally downstream of the worldly target. (2021, p. 51).

Boyd's understanding of the 'empirical' on the basis of the connection that experimental or observational results have with the real world is completely reasonable. At the same time, as Suárez's distinction between 'causal explanations' and 'theoretical explanations that employ causal vocabulary' entails, causal *stories* do not necessarily provide genuine cases of causal explanations, and thus causal stories cannot warrant the connection to the real world. They can be told without being true, and if they are not true the connection of the empirical results to the real world is not established. In other words, the empirical results whose connection to the real world is presented merely in a causal story cannot be said to be really connected to the world. Here I do not suggest that Suárez's distinction undermines Boyd's account of empirical results. Instead, Suárez's distinction clarifies that Boyd's account should not be interpreted in an antirealist way, according to which even causal explanations are stories that may not be true. I contend that her account needs to accept an experimental realist account of the causal connection between empirical evidence and unobservable reality.

The causal connections with reality enable us to distinguish evidence of real entities from unreal results. Empirical evidence is causally connected to properties of real entities. Accordingly, the contrast that Boyd makes between 'empirical' and 'virtual' or 'imagined' (see the quotation above) can be cashed out by appeal to real causal connections. These connections cannot be found in what Van Fraassen calls a 'public hallucination' such as the experience of a rainbow. According to him, by seeing through a scientific instrument such as a microscope, we see an image, which "could be *either* a copy of a real thing not visible to the naked eye or a mere public hallucination." He then prefers to "keep neutrality in this respect and just think of the images themselves as a public hallucination" (2008, p. 109). Van Fraassen maintains this neutrality in order to develop his antirealism about scientific instruments. It is, however, highly problematic to equate the images presented by scientific instruments with public hallucinations. We do not need to presuppose a colorful object in the sky to account for a rainbow. In explaining it, we do assume the existence, composition and dispersion of (white) light rays in the presence of water drops. Therefore, we consider these rays to be real; however, the explanation of the rainbow does not depend on a causal connection between some colorful object and our experience. In contrast, ions, for example, do need to exist to bring about the trace in the cloud chamber as their effect, and astrophysical entities such as gravitational waves have to exist to bring about the evidence detected by instruments such as the Virgo and LIGO detectors.

Van Fraassen maintains that "our instruments are *engines of creation*. They create new observable phenomena, ones that may never have happened in nature" (2008, p. 96). His view can be rephrased by Boyd's concept of empirical results as follows: new instruments typically produce unprecedented empirical results. By the advent of new technologies, novel scientific instruments are built to provide scientists with new empirical evidence. This is obviously correct (see also Record 2013; see also Van Eck and Barman this volume). However, Van Fraassen's claim to equate the image created by a scientific instrument with a public hallucination is controversial. His position cannot account for the actual practice of experimenters, who make a considerable effort to distinguish between empirical evidence and hallucinatory experience. Although hallucinatory results or mere artifacts of instruments may teach them something about the possible problems of the instruments, experimenters make efforts to distinguish between hallucinatory results (or mere artifacts) and the empirical results connected to the real world (see also Khalili 2022, section 5). The conditions of non-redundancy, material inference, and robustness, discussed in section 2, serve to philosophically articulate these actual efforts of experimenters (see my discussion of the cases of dark matter, digamma particles, Higgs bosons, and gravitational waves in Khalili 2023a, section 7). In the following, I focus on a particular practice of experimenters that helps them make sure that their obtained empirical results are robust evidence of real entities: the act of calibrating instruments.

Considering it to be "an important strategy for the establishment of the validity of an experimental result", Allan Franklin defines calibration as "the use of a surrogate signal to standardize an instrument". According to him: "If an apparatus reproduces known phenomena, then we legitimately strengthen our belief that the apparatus is working properly and that the experimental results produced with that apparatus are reliable" (1999, p. 237). Also, Slobodan Perović (2017, p. 317) characterizes calibration as "*any combination of experimental techniques that ensures the proper functioning of the apparatus based on already-known phenomena*".

Two types of calibration should be distinguished. In the first type, an instrument is compared with the same kind of instrument. For instance, a ruler can be calibrated using a standard reference ruler with clearly marked and verified quantitative units. In the second type, an instrument is calibrated by employing an apparatus the working method of which is different from that of the instrument to be calibrated. For example, the ruler can be calibrated using the 'time-of-flight' measurement method, in which an instrument emits a light pulse or electromagnetic wave towards the ruler, and then the length of the ruler is measured based on the time it takes for the pulse to travel from the beginning to the end of the ruler. Other methods of length measurement, such as (laser) interferometry, can also be used for extremely precise calibrations. This second type of calibrating is used to reproduce the same empirical results using (radically) different processes, so they provide replication techniques that ensure the proper functioning of the initial instrument. In the following I further highlight the importance of this type of calibration/replication techniques in scientific practice.

The importance of calibration is downplayed by what Harry Collins has called the 'experimenters' regress', the gist of which is that the use of experimental techniques cannot ensure the reliable functioning of an instrument inasmuch as the techniques rely on the assumption that the instrument functions properly. Collins (1985, p. 84) states that "we don't know if we have built a good detector until we have tried it and obtained the correct outcome! But we don't know what the correct outcome is until ... and so on *ad infinitum*." This circle, which Collins calls the 'experimenters' regress', constitutes the main argument of his *Changing Order* (1985).[4] It is obviously correct that the reliability test of an instrument cannot presuppose the reliability of the instrument. At the same time, it is equally correct that the use of other experimental techniques can ensure the reliable functioning of an instrument if the techniques are not based on the instrument itself. Accordingly, the circle between judgments of the validity of the instrument and judgment of the validity of a measurement result can be severed when the techniques are *independent* of the instrument and its proper functioning (see also Boyd 2021, section 4.1).

I would think that both sides of the debate on the so-called experimenters' regress agree that the 'circle' may *in principle* be avoided. The disagreement is mainly concerned with the question of whether, in specific actual experimental practices, the implemented calibration techniques depend on the proper functioning of the instruments to be calibrated. In the case of the detection of gravity waves, Collins claims that the outcomes of the detector are not checked by independent techniques, implying the relativist claim that social and political factors, such as negotiations or mechanisms of power relations, ultimately resolve disagreements about the reliability of the instrument. Franklin agrees that "calibration … was not decisive" in the case of gravity wave detection, but he convincingly argues that in this case "the regress was broken by reasoned argument". Moreover, he points out that "the case of gravity wave detection is not at all typical of scientific experiments" (1999, p. 14).

Considering discussions on the experimenters' regress, we can assess Van Fraassen's 'neutrality' between hallucination and the outputs of scientific instruments. This neutrality leads to the claim that the actual practice of calibration, or other replication techniques, cannot result in reliable evidence of real entities. This claim implies either that calibration and replication techniques *in principle* cannot result in reliable evidence of real objects or that they *in practice* cannot result in such evidence. The latter interpretation looks like Collins's argument against the reliability of experimental results, which

[4] Here I focus on Collins's 'circle', while his argument against the validity of experimental results also appeals to the role of 'tacit knowledge' in decisions made by experimenters (for a discussion of the latter part of his argument, see Feest 2016).

gives rise to a local skepticism regarding specific cases of the outputs of instruments. However, an antirealist attitude towards all unobservable entities is not a consequence of this skepticism, since experimenters may, in some cases, make use of independent techniques to calibrate the relevant instruments. In these cases, the obtained evidence will comply with the condition of robustness, which together with the conditions of 'non-redundancy' and 'material inference' can justify one's belief in the existence of some unobservable entity.

Otherwise, if Van Fraassen's claim is that calibration and replication techniques are *in principle* unable of resulting in reliable evidence of real entities, then a global skeptical attitude about the validity of the results of scientific instruments arises. According to this attitude, the epistemic value of instrumentally mediated empirical results is equal to that of public hallucinations. The main problem of this account is that it cannot remain empiricist anymore since it severs the crucial connection between reality and empirical results that any empiricist account must preserve. The results (or outputs of instruments) whose connection to the real world is questionable, or is drawn merely by a theoretical explanation that employs causal vocabulary, cannot be guaranteed to be really connected to the world. According to the understanding of the 'empirical' that makes an essential connection between 'empirical' evidence and the 'real' world, the results/outputs unconnected to reality, cannot be called 'empirical' anymore. A causal explanation is needed to connect empirical results to reality. Thus, empiricists must be committed to a kind of causal connection to reality: some causal connection must be presupposed between empirical evidence and unobservable entities. At the same time, our theoretical knowledge about these entities and of what the connection is might be incomplete or incorrect (this point is also made by Hans Radder, as I will discuss in section 4). Experimental realism highlights the *existence* of this connection, rather than how it should be described theoretically.

The distinction between 'existence' and 'whatness', which can be found in Avicenna's metaphysics, and also in medieval (Islamic) philosophy, may help to clarify the central claim of experimental realism. 'Existence' pertains to the question of whether something has effective being in reality. On the other hand, 'whatness' (quiddity or māhiyyat) pertains to the attributes that make something what it is. It delves into the nature and properties of a thing, regardless of whether it really exists. Fire burns because it has effective existence. We understand that fire is real as we perceive its real effects. The whatness of fire, on the other hand, describes the nature and properties of fire in different conditions. When fire burns us, we realize that something real has caused this burning, but our knowledge of the nature and properties of that thing may be incorrect. For instance, fire might be considered as one of the four elements alongside earth, air, and water, and not as a chemical reaction that involves the rapid oxidation of a combustible material in the presence of heat, oxygen, and a fuel source. Still, the fact that *that something,* which causes perceivable effects such as burning, must be *real* can hardly be denied, regardless of whether our knowledge of its whatness is complete or correct. Similarly, according to experimental realism, somethings that we now call ions must exist to bring about the evidence in the cloud chamber as their effect, or somethings that we call light rays must exist to causally explain the observable effects of the rainbow. We might be mistaken about the theoretical description of these light rays, but most probably not about the fact that somethings real, currently known as light rays, cause the observable effects.

In this section, I have problematized a way of dealing with the problem of whether instrumentally mediated empirical evidence is causally dependent on unobservable entities and argued that causal 'stories' that connect empirical evidence to reality should indeed provide causal explanations, rather than theoretical explanations that merely employ causal vocabulary. An implication of this argument is that antirealist empiricism is incoherent. Causal connections with unobservable reality must be presupposed by any empiricist account of instrumentally mediated empirical results. Accordingly, my suggestion is that an empiricist account of empirical results should accept the experimental realist view that the existence of unobservable entities is presupposed to casually explain empirical results. The next section will compare my view with another argument against antirealist empiricism.

4 Real Causes against Antirealist Empiricism

I have argued against antirealist empiricism and supported a causal interpretation of the connection between empirical evidence and unobservable entities. The present section discusses a further argument, presented by Hans Radder (2021), saying that the justification of empirical evidence itself already assumes a realist view of causation, which antirealist empiricism fails to provide. In the following, I begin by elucidating Radder's argument. Subsequently, I examine an apparent conflict between his argument and mine, clarifying that this conflict is not serious at all. Indeed, Radder's argument not only aligns with but also complements the viewpoints discussed in preceding sections. When considered together, our arguments synergistically amplify the criticism against antirealist empiricism.

Radder's argument is as follows. The interaction between the instrument and the object of inquiry can only be realized when a stable and reproducible correlation arises between the object and the final state of the instrument. In order to demonstrate the stable and reproducible correlation, potentially disturbing effects on the relationship between the instrument and the object must be excluded, by eliminating the disturbing factors or by shielding the instrument-object system against the disturbances. Accordingly, the interaction between the instrument and the object of inquiry can be realized only when potentially disturbing effects on the instrument-object system are excluded. Radder's central assertion is that the necessary elimination or screening of the relevant disturbances requires a realist interpretation of causation. An antirealist, empiricist interpretation in terms of a correlation makes doing science impossible.

Why can the problem of external disturbances not be addressed on the basis of an antirealist, empiricist account of causation? Radder responds that the impacts of external disturbances on the instrument-object system can only be understood as real causal relations. If the disturbing impacts are considered in terms of mere correlations, as empiricists wish, their elimination would mean that there must be no (significant) correlation at all between observable aspects of the environment and the instrument-object system. In this regard, we must first specify which of the *countless* potential correlations between the environment and the system are epistemically *relevant* in order to eliminate or screen their disturbing impacts. But the concept of correlation is helpless in this context. The relevant disturbances are those that *actually* disturb the system, not those that make (significant) correlations with the system. The core of his argument is that the empiricist alternative of removing all (significant) correlations between the environment and the instrument-object system is practically impossible because of the huge number of these correlations. Therefore, "it is only the notion of real causation that allows us to distinguish between relevant and irrelevant [disturbing] relations" (2021, p. 604).

Radder's argument is different from the argument I pursued in the previous sections. His reason for invoking real causation draws on the requirements to exclude external disturbances, while I have focused on the causal relation between instrumentally mediated empirical results and unobservable reality. A possible area of conflict concerns his account that in using an instrument for acquiring empirical knowledge of an object, a causal connection is sufficient but not necessary. According to him, the interaction between the object and the final state of the instrument should, at least, be a correlation (see his 1996, p. 11; 2021, p. 599). His (implicit) reason for this view is that historical and sociological case studies show that instruments can perform successfully, even when they work like black boxes: "the general point is that it is not always possible and not necessary to know the detailed causal process between the observed object and the final state of the instrument" (Radder, personal correspondence, 27 March 2023). This quote suggests that Radder has a specific meaning of causal versus correlational relations in mind. According to him, when one claims that A and B are causally connected, one should know the detailed causal process between A and B. By contrast, A can be in correlation with B even if the details of their relation are not known. In my view, Radder's point that in many cases the interaction between the object and the final state of the instrument is correlational (that is, they have interactions but the details of their interactions are not known) does not come into conflict with my claim. We should distinguish between these two questions:

I- Is instrumentally mediated empirical evidence causally dependent on unobservables?

II- Is it possible and necessary to know the detailed causal process between unobservables and their instrumentally mediated empirical evidence?

My positive answer to the first question relies on a specific meaning of causation in the context of experimental realism. This meaning is *existential*: the existence of a cause must be presupposed to explain the effect. This meaning is intended by Cartwright in 'causal explanation', by Suárez in 'causal warrant', and by Egg in 'material inference'. I also rely on this very meaning in my claim that empirical outcomes of scientific instruments are causally dependent on unobservable entities. This positive answer is *compatible with* a negative reply to the second question. The detailed causal process between the empirical results and the entity that they are evidence *of* is not always clear.

Radder's claim is not only compatible with, but also *complementary to,* my argument against antirealist empiricism. I focus on the relation between the object and (the outputs of) the instrument. His focus is on the relation between the object-instrument system and the environment. Overall, deploying different yet compatible and complementary arguments, Radder and I argue against the empiricist account that eschews real causation. Antirealist empiricism is incoherent because of two reasons. First, it cannot explain the exclusion of disturbing effects in empirical knowledge generation unless it presupposes an ontology of real causation. Second, the results of scientific instruments that are not causally connected to reality cannot be claimed to be empirical. For these reasons, empiricists have to accept (experimental) realism to remain coherent.

More generally, this chapter has shown that there are a range of important connections between debates on scientific realism and causation. In particular, the causal inference of unobservable entities from empirical evidence is of central importance to the project of entity/experimental realism. Studying experimental and observational practices relevant to scientific instrumentation and calibration, and to the exclusion of disturbing impacts on the instrument-object system, has pertinent implications for our comprehension of causal relations.

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Key massages:

- It is warranted to believe in the existence of an unobservable entity insofar as it can act as a non-redundant cause that is materially inferred from the evidence obtained in a variety of independent ways of detection.

- Instrumentally mediated empirical evidence is causally dependent on the existence of unobservable entities.
- Antirealist empiricism, which highlights the significance of empirical evidence but refrains from acknowledging its real cause, is incoherent.

Key readings:

Hacking, Ian. 1983. R*epresenting and Intervening: Introductory Topics in The Philosophy of Natural Science*. Cambridge University Press.

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