

Scientific Realism and Anti-Realism

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Abstract

What is the nature of science, what are its fundamental lessons about the nature of reality, and what is its relationship to subjectivity? This chapter provides an overview of the contemporary scientific realism debate and assesses how phenomenological ideas bear on it. It discusses the relationship between phenomenology and the individual sciences and explores the implications of phenomenological teachings concerning the horizontal structure of experience, the epistemic status of the life-world, and the mathematization of nature for our understanding of science. The author contrasts phenomenological approaches to science with objectivism, addressing how modern physics can be interpreted as supporting the former over the latter.

Keywords: scientific realism; unobservable entities; entity realism; perspectivism; horizon; life-world; mathematization

1. Scientific realism: An overview

In contemporary philosophy of science, scientific realism, roughly construed, is the stance that we should adopt a positive epistemic attitude toward scientific statements and take scientific theories at “face value.” Science provides knowledge of how the world works, can explain the observable phenomena, and we should embrace a realist attitude toward the entities postulated by science. More specifically, it is often distinguished along three dimensions of realist commitment (see Chakravartty 2007, 2017; Psillos & Ruttkamp-Bloem 2017): *Ontologically*, there is the commitment that the world investigated by the sciences exists mind-independently; *semantically*, realists are

committed to a literal interpretation of scientific theories; and *epistemologically*, realists champion the view that science provides us with knowledge of the world.

Typically, contemporary discussions focus on the status of the *unobservable entities* postulated by the sciences. Unobservable entities are characterized as entities that cannot be perceived with one's "unaided senses." Such unobservables implied to exist by our currently best scientific theories include proteins, atoms, and electrons. In this light, scientific realism can be understood as the threefold commitment that unobservable entities exist, that they possess the properties ascribed to them by our best scientific theories, and that we can know that they exist in the way described by those theories.

The most prominent versions of scientific anti-realism come in the form of instrumentalism. Instrumentalism, again roughly construed, is the thesis that scientific theories are mere predictive tools. They allow us to *predict* what we will observe, but they cannot *explain* the phenomena in terms of unobservable quantities. Instrumentalism in the form of logical positivism denies that statements about unobservable entities are meaningful sentences and rejects the idea that these statements have truth-values at all. They are not even false. By contrast, fictionalism treats unobservable entities as useful fictions. Scientific theories implying the existence of such entities are false, but due to their predictive success we should treat them as if they were true. Perhaps the most prominent contemporary anti-realist position is Bas van Fraassen's *constructive empiricism*. In an instrumentalist fashion, constructive empiricism declares *empirical adequacy* to be the primary objective of science. A scientific theory "is empirically adequate exactly if what it says about the observable things and events in the world is true" (van Fraassen 1980, 12). In contrast to logical positivism and fictionalism, constructive empiricism does not insist that statements about unobservable quantities are meaningless or false. Instead, an agnostic attitude is adopted. It is argued that even if unobservables exist and even if they have exactly the properties ascribed to them by the respective theories, we can never *know* this. Accordingly, the focus here is on the *epistemological* dimension of the scientific realism debate.

It should be clarified from the outset that realists will not say that just any theory that qualifies as scientific should be taken at face value, but only our currently best theories. Furthermore, they will typically not claim that scientific theories are true simpliciter, but that they *approximate* the truth. The better the theory, the closer it comes to a true representation of reality. Finally, and this is often not clearly emphasized in the philosophy of science literature, whatever it means to adopt a realist

attitude toward a scientific theory can only be clarified when considering the concrete theory in question. For instance, the wave function is the central object in quantum mechanics, but not all who would subscribe to a realist interpretation of quantum mechanics want to commit to taking the wave function as a physically real object. By contrast, QBism is generally considered an anti-realist interpretation because it not only denies that the wave function is real but also that it represents *anything* real. Quantum mechanics is not interpreted as a descriptive theory that tells us how real objects evolve in time. Still, QBists believe in the existence of an external world and in the existence of objects that cannot be perceived with one's unaided senses, such as electrons and photons. Furthermore, they deny that quantum mechanics is only about prediction and insist that it tells us important lessons about the nature of reality. This is to say that nobody should be a generic (anti-)realist about scientific theories. Instead, one's (anti-)realist commitments must always be specified in the context of the respective theory.

2. Standard arguments in favor and against scientific realism

It is often assumed that outside of academic discussions most people tend to be realists about science. And indeed, realism seems to suggest itself. This is due to the impressive achievements of science. We can send people to the moon, eliminate diseases through vaccines, make predictions that agree with experiments to an astonishing degree, and utilize highly complex theories such as quantum mechanics and general relativity in everyday technology. The success of science thus seems to command a realist attitude. This line of reasoning is now known as the “(no) miracle argument,” a term coined by Hilary Putnam, who argued that realism “is the only philosophy that doesn't make the success of science a miracle” (Putnam 1975, 73). It is generally considered the strongest argument in favor of realism. At its core, it is an abductive argument claiming that the *best explanation* for the various and impressive achievements of science is the assumption that our best scientific theories truthfully describe reality. After all, how could one explain, e.g., the functioning of an electron microscope without assuming the existence of electrons? Similarly, how to explain the enormous *predictive success* of quantum mechanics without assuming that it correctly describes reality in some substantial sense? The instrumentalist, of course, acknowledges the predictive success of our best theories, but according to the realist, the instrumentalist cannot adequately explain this success.

A further argument in favor of realism criticizes the distinction between the observable and unobservable. As noted above, scientific anti-realists typically agree that there is an external world

but restrict their ontological and epistemological commitments to the observable. That is to say, scientific anti-realists do not deny the existence of tables and chairs but reject that science provides us with knowledge of atoms and electrons. Accordingly, the anti-realist position depends on the assumption that there is a meaningful and well-motivated distinction between the observable and unobservable. This distinction is commonly understood as follows: “the observable is that which can, under favorable conditions, be perceived using the unaided senses (for example, planets and platypuses); the unobservable is that which cannot be detected this way (for example, proteins and protons)” (Chakravartty 2017).

Yet it seems random and quite anthropocentric to say I restrict my realist commitments to what I or humans in general can perceive with the naked eye. I cannot see bacteria with my unaided senses but already in the second half of the seventeenth century Antoni van Leeuwenhoek reported being able to observe bacteria under the microscope. By now, of course, it is standard to assume that bacteria can be seen with the aid of microscopes, and numerous impressive micrographs exist. To deny the existence of bacteria and similarly small objects would seem like denying the existence of lunar craters. Some healthy skepticism may have been reasonable when Galileo first reported observing them with his self-built telescope in 1609, but by now we have moved on. And indeed, anti-realists will typically not deny the existence of bacteria but treat them as a borderline case of the observable/unobservable distinction. Furthermore, different types of unobservable entities – such as bacteria, quarks, quantum fields, black holes, dark matter, and absolute space – are unobservable for very different reasons. Anti-realists may restrict their skepticism to those quantities that are unobservable in a more profound sense than simply being too small for the human senses to be detected. We will return to this in Section 3.2.

The two main arguments against realism are the *pessimistic meta-induction* and the *problem of underdetermination*. Both arguments are powerful and have forced realists to refine their position in various ways. The pessimistic meta-induction aims at an *empirical* refutation of realism. The problem of underdetermination raises many systematic problems based on the fact that scientific theories, including our currently best ones, are underdetermined by empirical data.

The pessimistic meta-induction proceeds as follows. Scientific realism holds that one should regard our current best theories as correct. But the history of science is a history of superseded theories: theories that turned out to be wrong and were replaced by new ones. Entities that were once considered real but later abandoned include phlogiston, caloric, and the luminiferous aether. What,

then, makes our current best theories and ontological commitments better than our past ones? Applying inductive reasoning, we should conclude that they too will eventually turn out to be wrong. The optimistic response of the realist is that the history of science is a history of *approximating* the truth. Our current best theories may turn out to be wrong, but they are closer to a true representation of reality than their predecessors. Furthermore, in the face of theory change and the history of superseded theories, realists have sought to articulate versions of scientific realism that are less vulnerable to the pessimistic meta-induction. The idea is to identify elements of scientific theories that remain invariant under theory change and to be realist about these invariants. The most prominent versions of such a selective realism are entity realism and structural realism. Entity realism is particularly close to certain ideas we find in phenomenology, and in recent years phenomenologically minded philosophers of science have attempted to develop and refine entity realism on the basis of phenomenological insights. We will discuss this in Section 3.3.

Anti-realist objections based on the *underdetermination* of theory by data point to how difficult it is to read off a clear ontology from a theory. What makes the problem of underdetermination particularly interesting and pressing is that it is not merely a theoretical possibility. On the contrary, empirical underdetermination is ubiquitous in modern physics. “[E]very theoretical physicist who is any good knows six or seven different theoretical representations for exactly the same physics. He knows that they are all equivalent, and that nobody is ever going to be able to decide which one is right at that level, but he keeps them in his head, hoping that they will give him different ideas for guessing” (Feynman 1965, 168). Notably, empirical underdetermination comes in many forms.

First, one and the same theory can be interpreted in many different ways. Quantum mechanics is the prime example: different interpretations can lead to radically different pictures of reality. For instance, according to the many-worlds interpretation, reality branches every time a quantum event takes place, such that every possible outcome is realized in a different branch of reality. In this picture, there are infinitely many parallel worlds. By contrast, according to textbook quantum mechanics, there is only one world, and every time a measurement occurs the wave function “collapses” to one of its eigenstates. This collapse, in turn, can itself be interpreted in many different ways. For example, some early pioneers of quantum mechanics believed that the collapse is a physical process somehow caused by the *consciousness* of the observer. QBism, by contrast, holds that the wave function does not represent external reality but an agent’s beliefs about future measurement outcomes, and that the collapse is not a physical process but an update in one’s belief system. The point here is that the same theory can be interpreted in many different ways, with no

empirical guidance as to which interpretation to prefer. It should also be emphasized that we don't have to invoke fancy quantum mechanics to point out that physical theories are in need of interpretation. One crucial concept here is that of *symmetry*. Symmetries are ubiquitous in nature and physical theories. In the case of good old classical mechanics, due to the symmetries of the theory, one could assume either that the entire material universe is at rest or that it is moving with some constant velocity in an arbitrary direction. There is no possible empirical observation that would allow to prefer one assumption over the other.¹

Second, the same theory can be formulated in mathematically different ways. Standard formulations of classical mechanics suggest that point particles in three-dimensional space are the fundamental objects of the theory. However, the dynamics of classical mechanics can also be formulated via the so-called Hamilton-Jacobi equation. This formalism suggests a very different physical picture: the fundamental mathematical space is $3N$ -dimensional configuration space, the fundamental objects are scalar fields defined on that space, the Hamilton-Jacobi equation tells you how these fields evolve in time, and particle trajectories emerge as non-fundamental objects derived from these fields. What this paragraph and the previous one demonstrate is that even if one wants to be a realist about some scientific theory, it is often not clear what to be realist about.

Third, perhaps most interestingly, we have *dual theories*: different but empirically equivalent theories that are mathematically distinct in the sense that they operate with different theoretical entities but are still mathematically equivalent in the sense that one can map one theory onto the other.² Duality is often understood as an isomorphism between theories. The most widely discussed example is AdS/CFT duality. In this case, a gravitational string theory on a five-dimensional curved spacetime is empirically equivalent to a non-gravitational quantum field theory on a four-dimensional flat spacetime. This case is so interesting because the dual theories suggest radically different ontologies. If you are a realist and want to read off an ontology from your theories, should you believe to live in a five-dimensional curved spacetime or a four-dimensional flat one?

Fourth, we have non-dual but empirically equivalent theories (or, if not strictly equivalent, then empirically sufficiently similar such that the available data do not allow to prefer one over the other). Consider, for instance, Ptolemaic astronomy versus Newtonian cosmology. According to the

1 In the famous Leibniz-Clarke debate, this was one of the reasons why Leibniz rejected Newton's interpretation of space as an absolute space. See van Fraassen (1980, 46-55) for a discussion of this in the context of the scientific realism debate. A related problem at the center of contemporary philosophy of physics is how to interpret gauge symmetries/theories (see Berghofer et al. 2023).

2 For philosophical reflections on dual theories, see, e.g., (De Haro and Butterfield 2025).

former, the Earth is at the center of the universe, and the planets circle it according to a deferent-epicycle model. Epicycles are very effective because with a sufficient number of them any smooth curve can be approximated to arbitrary accuracy. This is to say that, with respect to the observed motion of the planets, Ptolemaic astronomy can be made empirically equivalent to Newtonian cosmology. From the present-day perspective, the Ptolemaic epicycle system may seem absurd, but (especially in light of the pessimistic meta-induction mentioned above) it must be emphasized that it was accepted by European and Islamic astronomers for over a millennium.

In all these cases 1-4, we have interpretations, formulations, or theories that are empirically equivalent. No experimental guidance can be offered for preferring one over the other. What non-empirical criteria, then, do we have for dealing with the problem of underdetermination? The most popular choices are parsimony as well as predictive and explanatory power. These criteria allow to prefer Newtonian cosmology over Ptolemaic astronomy. Epicycles are effective at modeling the observed motion of planets, but they are arguably overly complicated and, more importantly, limited in predictive and explanatory scope. In particular, the deferent-epicycle system is silent on everything that does not concern the behavior of planets. By contrast, Newtonian gravitation derives both planetary trajectories and terrestrial free fall from a single quantitative law, thereby achieving explanatory unification and cross-domain predictive scope absent in the Ptolemaic framework. This is why Newtonian cosmology is the better theory.

Now, while the criteria of predictive and explanatory power work well in this particular case, they cannot be applied equally well to the cases 1-3 mentioned above, namely to different interpretations or formulations of the *same* theory, or to dual theories. This leaves us with the criterion of parsimony. But parsimony is difficult to quantify and often the same interpretation/formulation/theory is parsimonious in one respect but not in another. The many-worlds interpretation of quantum mechanics is a nice example. Regarding its formalism, it is often said to be more parsimonious than textbook quantum mechanics because it posits only a single dynamical equation, i.e., the Schrödinger equation. No collapse postulate is required since the wave function never collapses. However, in terms of the number of entities it implies to exist, it is the least parsimonious interpretation, as it implies infinitely many parallel worlds. Yet some proponents would argue that, at a fundamental level, it is ontologically parsimonious because fundamentally there exists only the universal wave function (and the space on which it is defined).

By discussing the problem of underdetermination in some detail, I hope to have shown that even if one wishes to take a scientific theory at “face value,” it can be remarkably difficult to specify what this is supposed to mean. Furthermore, the discussion of underdetermination is also useful for approaching the debate between standard scientific realism and perspectival realism. Standardly, scientific realists assume that if there are multiple scientific models/representations of the same physical situation, at most one can be the correct description of reality. Perspectivists, by contrast, maintain that scientific knowledge is always perspectival, and that different – and even mutually inconsistent models – can be equally valid, each representing an aspect of reality, none describing reality exhaustively. Phenomenology and perspectivism share many common ideas and commitments. Indeed, I would say that any genuinely phenomenological approach to science constitutes a version of perspectivism. We will discuss this in more detail in Section 3.4.³

3. Phenomenology and the scientific realism debate

3.1. Phenomenology, its relationship to the sciences, and objectivist realism

The relationship between phenomenology and the individual sciences is as intimate as it is complex. When Edmund Husserl inaugurated the phenomenological tradition, his aim was to introduce and establish phenomenology as a rigorous science. While other disciplines, such as mathematics and physics, had already developed methodologies and basic theorems that were widely accepted by practitioners in their respective fields, philosophy lacked such a foundation. In this sense, the sciences served as a role model for phenomenology. On the other hand, it was clear to Husserl that one must not make the mistake of believing that the methods that serve so well in the individual sciences are also adequate for philosophy. Phenomenology was conceived as the most fundamental science, the science of sciences, the first philosophy that clarifies also the validity of the individual sciences. To be sure, for Husserl it was never in doubt that the sciences produce knowledge and that their methods are adequate; however, what was very much in question was what gives scientific knowledge its special epistemic status and why the respective methods are justified. In physics, for instance, observation, experimentation, deduction, and induction are permissible methods for gaining knowledge, but physics itself cannot explain why these methods are valid. As Heidegger put

3 It must be emphasized that the focus in this chapter is on physical theories. Taking a theory at face value will be much more straightforward in other sciences with less mathematics involved. For instance, for the hypothesis that the mass extinction of the non-avian dinosaurs was caused by an asteroid crashing earth it is quite clear how to understand this literally. Similarly, when science tells us that present-day global warming is caused by human activities. The same goes for the prediction that millions of people will die in the next few years as a direct consequence of the human-caused rise in global temperatures.

it, “The moment we talk ‘about’ a science and reflect upon it, all the means and methods of this science in which we are well versed fail us” (Heidegger 1967, 177). This is true of biology, where we “cannot put biology under the microscope” (Heidegger 1967, 177), as it is of physics, which “itself is not a possible object of a physical experiment” (Heidegger 1977, 176). The question of why perceptual experiences are a source of knowledge is a philosophical-epistemological question, not one that can be answered by the methods of the empirical sciences.

Phenomenology, roughly speaking, is the study of the structures of consciousness, conscious experience in particular. More specifically, it is, or at least aims to be, a *descriptive* and *eidetic* study of consciousness. It is descriptive in that it is pursued from the first-person perspective. It is eidetic in that it is pursued a priori, seeking to unveil the structures that underlie any possible consciousness. Now, how can phenomenology, the study of the structures of experience, fulfill its ambition to be the most fundamental science that clarifies the epistemological foundations of all scientific knowledge?

The Husserlian answer to this question can be roughly summarized as a three-fold line of reasoning. First, every piece of knowledge, including scientific knowledge, is based on subjective experiences. Here we understand experience in a broad sense, encompassing perceptual experiences as well as introspective experiences and a priori intuitions. Second, such justification-conferring experiences gain their justificatory force by virtue of internal factors, specifically their character of originary givenness. Third, phenomenology is the discipline that studies the intentional structure of experience, including the various types of originary givenness.

In this sense, *subjectivity* is the ultimate source of justification for any natural science (see Husserl 1984, 120). Of course, this does not mean that phenomenology can provide the laws of physics or of any other individual science. What it does mean is that the justification for believing in any law of nature ultimately depends on originary presentive acts, such as visual experiences (see Husserl 1973a, 121). It is the task of phenomenology, then, to clarify why such experiences have justificatory force and how the laws of nature can be justifiably derived from them. Of course, most experiments in the natural sciences are too complex and sophisticated for our perceptual experiences to directly present the objects in question. What we typically observe instead are the outputs of measuring devices. In this sense, Husserl says that “the inductive scientific judging” of the “exact objective sciences that by going beyond the immediately experienced infers the non-experienced is always dependent on its ultimate legitimizing basis, on the immediate data of

experience” (Husserl 1973a, 121; my translation). In the *Crisis*, he puts it as follows: “Straightforward experience, in which the life-world is given, is the ultimate foundation of all objective knowledge” (Husserl 1970, 226). The life-world is the world of our everyday experiences, the world of tables and chairs. It is Husserl’s conviction that the life-world and our everyday experiences constitute the epistemological foundation of the individual sciences. Accordingly, for Husserl, our interpretation and understanding of scientific theories must be consistent with the reality of the life-world.

We can now already see why phenomenology must be skeptical about the kind of objectivist realism that was adamantly defended by several key figures in analytic philosophy. The following passage by Wilfrid Sellars expresses a view that remains prominent in contemporary philosophy of science:

But, *speaking as a philosopher*, I am quite prepared to say that the common sense world of physical objects in Space and Time is unreal—that is, that there are no such things. Or, to put it less paradoxically, that in the dimension of describing and explaining the world, science is the measure of all things, of what is that it is, and of what is not that it is not.⁴ (Sellars 1963, 173)

In this spirit, by objectivist scientific realism I understand the view that science delivers an exhaustive and purely objective third-person description of reality. All that exists is the world as described by our best fundamental theories. Since modern physics represents reality very differently from our ordinary experience, objectivist scientific realism implies that our experiences are misleading and that ordinary objects are unreal. For Sellars, the world of our everyday experiences is an illusion. What truly exists are not tables and chairs, but entities such as elementary particles and quantum fields. Ironically, this form of objectivist realism thus entails an *anti*-realist attitude toward precisely those entities with respect to which it is most natural for us to be realists. We will address Husserl’s critique of the mathematization of nature in Section 3.4. For now, it suffices to emphasize that phenomenology is incompatible with objectivist realism, but also that realism is not necessarily objectivist realism.

4 De Caro lists several contemporary proponents of the view that “only one true and complete description of the world exists, which is typically regarded as being offered by the natural sciences, especially physics” in (De Caro 2020, 58).

3.2. The principle of all principles and unobservable entities

In the previous subsection, we discussed that phenomenology is centered around the notion of experience. One place in which Husserl puts special emphasis on the epistemological role of experience is his *principle of all principles*.

No conceivable theory can make us err with respect to the *principle of principles: that every originary presentive intuition is a legitimizing source of cognition, that everything originally (so to speak, in its ‘personal’ actuality) offered to us in ‘intuition’ is to be accepted simply as what it is presented as being, but also only within the limits in which it is presented there.* (Husserl 1982, 44)

This implies that every originary presentive intuition is a source of immediate justification. Furthermore, Husserl stresses that originary presentive intuitions are our most fundamental justifiers (1982, 36). In other words, every piece of knowledge and epistemic justification can be traced back to originary presentive intuitions. Perceptual experiences constitute a subset of such experiences. They are originally presentive in the sense that they present their objects “in the flesh” (Husserl 1984, 458) or as “bodily present” (Husserl 1973b, 14).

As discussed in Section 1, a large part of the scientific realism debate focuses on *unobservable* entities, with scientific anti-realists denying that science can provide us with knowledge of them. Husserl’s experience-centered epistemology seems to align well with an anti-realist empiricist position. Specifically, it has been argued that Husserl is particularly close to van Fraassen’s constructive empiricism (Wiltsche 2012, 2017).⁵ Emphasizing that “[i]t is nearly impossible to overestimate the importance of” the principle of all principles, Wiltsche argues that Husserl’s basic epistemological theses lead to a version of scientific anti-realism that “is not ontological, but epistemological in nature,” in the sense that we must adopt “an agnostic stance with regard to existential claims about unobservable entities such as ‘atoms, ions, and the like’” (Wiltsche 2012, 112).

Wiltsche (2017) further distinguishes between three types of unobservables: objects that cannot be observed due to their location in space (such as a rock on Venus), objects that cannot be observed due to their position in time (such as an event in one’s past), and objects that cannot be observed due to their size (such as atoms, electrons, and ions). Wiltsche argues that phenomenological-

⁵ For a qualification of this alliance, see Wiltsche (2017, note 9).

epistemological principles are consistent with realism about the former two kinds of unobservables, but not about the latter. Regarding the rock on Venus, it is quite straightforward to assume that it would, in principle, be possible to observe it – we could go there. Past events can also be observable, given the finite speed of light. However, regarding atoms, electrons, and ions, “[b]ecause they are too small, it is impossible for them to become present in acts of direct, immediate perception” (Wiltsche 2017, 822).

There are five possible counterarguments I want to address. First, the focus on objects that are too small seems somewhat arbitrary. What about fields, black holes, dark matter, etc.? Of course, this is less an objection than a call for further elaboration. Second, it is unclear how small an object must be to count as unobservably small in the relevant sense. Most bacteria are too small to be visible to the unaided eye, but it seems nobody wants to be anti-realist about them. The typical counter-counterargument is that most of our concepts are vague and admit of gray areas, and that this also applies to the notion of the “unobservable”: while there may be debatable cases, there are also clear-cut cases such as atoms and electrons.

Third, it seems anthropocentric to say that we should be anti-realist about objects that are too small for us to observe. Some birds can sense the Earth’s magnetic field via cryptochrome proteins in their retinas. Do they thereby *observe* the magnetic field? That’s similarly hard to tell as what it’s like to be a bat. Wiltsche (2017) discusses the objection that many “unobservables” could be perceived if human eyes functioned like electron microscopes. Drawing on Husserl’s account of horizontal intentionality and the distinction between motivated and empty possibilities, he argues that this is merely an empty possibility and therefore lacks epistemic force.

Fourth, also drawing on Husserl’s account of the horizontal character of experience, some phenomenologically minded philosophers of science have argued that in certain cases the use of scientific instruments resembles embodied perception and that even if “unobservables” cannot be originally given, they can be co-given and thus experienced in a way that allows us to justifiably believe in their existence. We will discuss this in more detail in the next section. Fifth, it should be noted that Husserl’s principle of all principles does not entail that we can know only what can be originally given. What it does say is that every originary intuition is a source of justification. The accompanying principle we discussed states that only originary intuitions can be a source of immediate justification. Of course, this leaves room for the claim that we can *inferentially* justify belief in entities that cannot be originally given. This is not to deny that there is textual evidence

suggesting that Husserl endorsed a restriction of ontological commitment to objects that can, in principle, be originally given. But is this restriction systematically plausible? Certainly, we allow for inferential justification, and certainly Husserl acknowledged that, in the sciences, we proceed via various kinds of inference, such as deduction, induction, and abduction. So why should we rule out the possibility that we can have compelling inferential justification to believe in entities we cannot observe? For more details on this line of reasoning, see Berghofer (2017).

3.3. Horizontal intentionality and entity realism

As mentioned above, phenomenology is the study of the structures of experience. One structural feature at the center of phenomenological analysis is *intentionality*: experiences are always about something that is (re)presented. Original givenness, discussed in the previous subsection, is a crucial feature of justification-conferring experiences. A further feature revealed by the phenomenological analysis of the intentional structure of experience is that perceptual experiences, for instance, also exhibit a *horizon of co-givenness*. In other words, experiences are horizontally structured. This denotes the phenomenal fact that experiences go beyond what is directly given. Experiencing is always an “*intending-beyond-itself*” (Husserl 1960, 46).

Horizontal intentionality can be illustrated as follows. Assume that you are looking at a cup of coffee. At first glance, what presents itself to you in experience is a three-dimensional object in space. However, closer examination reveals that what is strictly sensuously given to you is not simply a cup and its content, but only *one single profile of the object*, its current front side. Of course, you could move around the cup and make the current back side the new front side. But this doesn't change the fact that the cup is always given *in perspectives*, and that, more generally, the objects of perceptual experiences always have more parts, functions, and properties than can be actualized in a single intentional act. As Michael Madary puts it, “Visual perception is an ongoing process of anticipation and fulfillment” (Madary 2017, 3). When looking at your cup, you have certain anticipations of how it will feel when you grab it and how it will look from different perspectives. These anticipations can be fulfilled in new perceptual experiences, which will in turn trigger further anticipations. Importantly, the perspectival character and horizontal structure of experience are not mere flaws of human perception but fundamental characteristics of experience.

The concept of horizontality is closely related to the concept of *embodiment*. When I anticipate how the cup will look as I move around it, how it will feel when I touch it, and so on, I implicitly

experience myself as an embodied subject capable of physically engaging with the object. Now, it has been argued that scientific instruments can function as extensions of the experimenter's body, such that one can experience scientific entities in the sense that one forms anticipations of what one will experience when operating the instrument in certain ways, and these anticipations can be fulfilled. This position resonates well with Merleau-Ponty's famous example of the blind man's stick: "The blind man's stick has ceased to be an object for him, and is no longer perceived for itself; its point has become an area of sensitivity, extending the scope and active radius of touch, and providing a parallel to sight" (Merleau-Ponty 2002, 165). In the context of his "horizontal realism," Heelan summarizes this approach regarding scientific instruments as follows:

Now the position I have been defending is that theoretical states and entities are or become directly *perceivable* (alternatively, 'observable,' in the stipulated sense) because the measuring process can be or become a 'readable technology,' a new form of embodiment for the scientific observer (Heelan 1983, 203).

It has been argued that Heelan's horizontal realism shares similarities with contemporary forms of *entity realism*, and that the latter could benefit from phenomenologically motivated modifications. In what follows in this subsection, I will briefly introduce entity realism and show how phenomenologically minded philosophers of science aim to refine and improve it.

Entity realism comprises a positive and a negative thesis. The positive thesis holds that, under certain circumstances, one should adopt a realist attitude toward the entities postulated by science. The negative thesis maintains that one should adopt a skeptical attitude toward the theories describing these entities. The rationale is that the objects described by different theories tend to be more stable than the theories themselves. An example often discussed in this context is the electron. Since it was first posited, many theories concerning its precise nature have come and gone, but the electron itself is here to stay. Virtually no one in the physics community still endorses the Rutherford-Bohr model of the atom, yet almost everyone accepts the existence of electrons and atoms.

Entity realism, however, does not unqualifiedly assert that all the entities postulated by the sciences exist. Rather, it claims that under certain circumstances we are epistemically justified in believing in the existence of unobservables. The question, then, is how these circumstances are to be specified. The most common approach holds that realist commitment should be restricted to those entities that

we can *causally manipulate*. In the famous words of Ian Hacking, “if you can spray them, then they are real” (1983, 23). An example often discussed in this context is laser technology. A laser operates by exciting electrons in atoms. An electron absorbs energy, is thereby excited to a higher energy level, and eventually emits a photon. This process of spontaneous emission is a quantum-mechanical effect and key to numerous applications. Since in this example we make electrons absorb energy and emit photons, we causally manipulate them. Entity realism therefore suggests we should believe in their existence, which is indeed the widespread consensus in science.

One problem with entity realism is that it is unclear whether the belief in a scientific entity can be separated from the belief in the theory describing this entity. In our laser example, what do we believe in if we believe in the existence of the electron but not in quantum mechanics? If two empirically equivalent theories characterize “the” electron in radically different ways, do two experimenters who manipulate “electrons” on the basis of different theoretical backgrounds believe in the existence of the same object? What is the electron without theoretical context? Another worry is that the criterion of causal manipulability does not seem applicable to astronomical objects. Galileo could observe craters on the Moon, but he could not manipulate them. Yet we have compelling evidence for the existence of supernovae, black holes, and the like, even though there is no straightforward way to manipulate them as we do objects in the lab.

Still, with the criterion of causal manipulation at hand, entity realism will be attractive to those who are sympathetic to standard realism but do not want to ontologically commit to abstract objects such as absolute space, wave functions, or configuration space. Indeed, the focus on experimental practice resembles the phenomenologist’s emphasis on embodiment, and, as mentioned above, there is a rich tradition in phenomenology that highlights the epistemological significance of technologically mediated observation (Heelan 1983, Ihde 2012, Vallor 2009, Khalili 2022). Vallor (2009) emphasizes the similarities between Heelan and Hacking, arguing for a phenomenological version of entity realism centered on the notion of *explorability* rather than manipulability (see also Khalili 2022). One virtue of this account (at least from the realist’s perspective) is that it is better suited to accommodating astronomical objects that cannot be easily manipulated. Since a phenomenological version of entity realism crucially rests on the concepts of horizontality, it also bears resemblance to another approach that recently gained momentum in the scientific realism debate: perspectival realism.

3.4. The life-world, subjectivity, and perspectival realism

In Section 3.1 we defined objectivist realism as the view that science delivers an exhaustive and purely objective third-person description of reality. We pointed out that this position is in tension with phenomenology insofar as it suggests that our everyday experiences and our life-world are illusory. The worry was epistemic in nature: everyday experiences constitute the epistemic foundations of science, so it would be self-undermining to interpret science as revealing that experiences are epistemically defective. This worry concerns the objectivist assumption that science delivers an *exhaustive* description of reality and is intimately related to Husserl's famous critique of the mathematization of nature. The quintessence of this critique is his warning against "taking for true being what is actually a method" (Husserl 1970, 51). The fact that we can so successfully represent (at least parts of) nature by means of mathematical methods and symbols is impressive and deserves admiration as well as critical reflection, but we must not make the mistake of confusing mathematics with physical reality. We can use mathematical models to represent reality, but this does *not* imply that they *constitute* reality. In the context of the *Crisis*, this means that we should reject the (purportedly) Galilean thesis that reality literally consists of and is exhausted by geometrical-mathematical objects. Such questions concerning the mathematization of nature remain highly topical, for instance in the context of quantum mechanics and wave function realism.⁶

The previous paragraph concerned the objectivist thesis that the sciences deliver an exhaustive picture of reality. However, the claim that the sciences are purely objective is at least as problematic for phenomenologists. In the previous subsection, we discussed the horizontal structure of experience, emphasizing that, for the phenomenologist, the perspectival character of perception is not due to a shortcoming of human beings but an essential feature of perception. Many phenomenologists and contemporary perspectivists argue that scientific theories are perspectival in a similar sense. A central and recurring claim in Husserl's philosophy of science is that the life-world is the meaning-fundament of the natural sciences (see Husserl 1970, §9h). Since the life-world is epistemically constituted by our experiences, and since our experiences are perspectival in character, this suggests that our scientific theories, too, are perspectival. More specifically, phenomenologists typically acknowledge that subjective factors influence our theoretical reasoning in various ways. For one thing, we all are subjects embedded in and shaped by *society* and *culture*.

6 See, e.g., Berghofer 2022, Section 15.5.2; Berghofer et al. 2020; Berghofer & Wiltche (forthcoming).

But I am a 'child of the times'; I am a member of a we-community in the broadest sense—a community that has its tradition and that, for its part, is connected in a novel manner with the generative subjects, the closest and the most distant ancestors. And these have 'influenced' me: I am what I am as an heir. (Hua XIV; cited in Zahavi 2003, 138)

Importantly, as Husserl emphasizes in the *Crisis* and in “The Origin of Geometry,” this also holds for scientific theories. Science is a *historical process* and our scientific notions, practices, and symbols are likewise *inherited* in important ways. More generally, for many phenomenologists the very practice of science is inseparable from the perspective of the subject who experiences and theorizes. On this view, the natural sciences can never achieve a purely objective, third-person standpoint (see, e.g., Zahavi 2019, 54).

An approach to the scientific realism debate that recently gained traction and shares with Husserl the emphasis on the perspectival character of experience and science is perspectival realism, or perspectivism. Broadly speaking, perspectivism aims to rethink the nature and scope of scientific theories and models, arguing that reality cannot be viewed from nowhere or from no perspective whatsoever. Michela Massimi defines perspectivism as denoting “a family of positions that in different ways place emphasis on our *scientific knowledge being situated*” (Massimi 2018, 164), emphasizing that scientific knowledge is always “knowledge from a human vantage point” (Massimi 2018, 166). By “being situated,” Massimi means that scientific theories are always “*historically situated*” and “*culturally situated*” (Massimi 2018, 164). The main proponents of perspectival realism include Giere (2006), Massimi (2018, 2022), and Teller (2011, 2020).⁷

One common objection to perspectivism is that depending on how precisely it is spelled out what it means for scientific theories to be “perspectival,” perspectivism either collapses into anti-realism or standard realism. If the claim is that scientific facts themselves are non-objective or perspectival, then the objection is that this amounts to a form of anti-realism. If, by contrast, the perspectivist more modestly intends only to emphasize that our scientific theories are products of human agents who are fallible, limited, and influenced by subjective factors, then the objection is that this is not necessarily incompatible with a moderate version of objectivist realism – one that accepts that even our most successful scientific theories may turn out to be wrong.

⁷ Van Fraassen (1980) is sometimes considered an anti-realist version of perspectivism.

In my view, the most promising strategy for phenomenologists and perspectivists to articulate a genuinely perspectival position that avoids collapsing into either standard realism or anti-realism is to take guidance from modern physics in spelling out how objectivism fails. If our currently best and most fundamental scientific theories themselves suggest that objectivism is mistaken, then the realist credo to take science seriously would compel us to abandon objectivist scientific realism. We will discuss this in the next section.

4. Phenomenology and modern physics

The question to be addressed in this final section is whether modern physics itself supports a phenomenological-perspectivist alternative to objectivist realism. This is an extremely involved question, as there is no consensus at all on how to interpret a theory such as quantum mechanics. However, what is clear is that relativity theory and quantum mechanics have crucial implications for how to understand science and nature, and that these theories are often taken to undermine objectivism. While classical physics is generally considered the prime example of a scientific theory that delivers an objective description of how external reality evolves in time, modern physics challenges such a picture of science. This is because it emphasizes operational notions such as measurement, challenges the idea of an observer-independent reality, and forces us rethink the concept of time. Only recently, but better late than never, have contemporary phenomenologists begun to systematically investigate phenomenological approaches to modern physics, inquiring whether and how phenomenology can contribute to making sense of theories and concepts such as general relativity, quantum mechanics, and the gauge principle. I will provide an overview of this development and conclude by pondering the question of what it would mean for the scientific realism debate if taking our most fundamental scientific theories at face value were to undermine certain realist commitments.

Although Husserl himself never worked on anything like a phenomenological interpretation or grounding of quantum mechanics or relativity theory, we know from his correspondence that he was greatly interested in and highly appreciative of such projects. In particular, he supported the work of his pupil Oskar Becker, who aimed at a phenomenological grounding of general relativity. In a letter to Weyl, Husserl wrote:

It [Becker's *Habilitation*] is nothing less than a synthesis of Einstein's and yours discoveries with my phenomenological investigations on nature. [...] What will Einstein say when it is shown that

nature requires a relativity-theoretical structure on the *a priori* grounds of phenomenology and not on positivistic principles, and that only in this way a completely understandable, and ultimately exact, science is possible. (Husserl in Mancosu & Ryckman 2005, 160f.)

Besides Becker, the classical phenomenologist most engaged with modern science, arguing that phenomenology and science can complement each other, was Merleau-Ponty. According to him, relativity theory refutes the idea of “absolute and final objectivity” as well as “the notion of an absolute observer” (Merleau-Ponty 2004, 44f.), and quantum mechanics in particular shows that science is not about objective reality but about the relationship between subject and object (Merleau-Ponty 2003, 85; 1968, 15). While in Husserl and many other phenomenologists we find the idea that science can never be purged of all subjective factors, Merleau-Ponty goes a step further by arguing that the sciences should *actively incorporate the first-person perspective* (Merleau-Ponty 1968, 27).

What makes the relationship between modern physics and phenomenological ideas particularly interesting is that not only can the former be interpreted as supporting or complementing the latter, but the latter have actually had an impact on shaping the former. The prime examples here are crucial achievements of Hermann Weyl and Fritz London. In Weyl’s case, phenomenological ideas played a heuristic role when he introduced the gauge principle, one of the most important pillars of modern physics (see Ryckman 2005, 2020). In London’s case, phenomenological ideas shaped his influential interpretation of quantum mechanics, according to which “the idea of an observable world, totally independent of the observer, was a vacuous idea” (London & Bauer, 1983, 220; see also French 2023).

From a phenomenological perspective, the development of modern physics could be understood as a continuous radicalization of the idea that the experiencing subject cannot be ignored by but must be incorporated into our fundamental scientific theories. In this light, relativity theory teaches us that there is no absolute or privileged perspective: each reference frame, which we may conceptualize as an “observer,” is on equal footing. The gauge principle, in Weyl’s original sense, rests on the idea that every space-time point “can be considered the locus of an experiencing, constructing ego” (Ryckman 2020, 268). Again, the perspective of each “observer” must be treated as equally valid, so our theories must be invariant under *local* transformations. Textbook quantum mechanics puts the final nail in the coffin of objectivism by literally incorporating the operational notion of “measurement” into the axioms of the theory.

Many recent developments in the foundations of quantum theory can be understood as further undermining objectivism. The success of the quantum reconstruction program, in which the formalism of the theory is derived from information-theoretic principles, further emphasizes the operational nature of quantum mechanics (see Goyal 2023, Berghofer 2024a, 2024b). Certain no-go theorems “for observer-independent facts” can be interpreted to “indicate that in quantum theory, we can only define facts relative to an observation and an observer” (Brukner, 2018, 2).⁸ Finally, in QBism we have a consistent interpretation of quantum mechanics in which the experiencing subject takes center stage and in which it is explicitly rejected that the formalism delivers a description of external reality. Instead, the formalism is a tool that allows the subject to make better predictions about the contents of their future experiences (see, e.g., Fuchs 2023).

It must be emphasized, however, that although phenomenological approaches to physics have recently gained momentum, they remain clearly outsider positions. Contemporary philosophy of physics is dominated by objectivist accounts. Regarding the interpretation of quantum mechanics, most philosophers subscribe to one of the three so called “quantum theories without observers”: the many-worlds interpretation, Bohmian mechanics, and objective collapse theories. What is clear, however, is that every interpretation comes with a cost in the sense that it entails some counter-intuitive consequences. One price to be paid by QBism and similar agent-centered interpretations is that we must give up the idea of a purely objective science that provides a third-person description of how external reality evolves in time. Of course, for many phenomenologists this is not a bug but a feature.

Now, for the sake of argument, let us assume that phenomenological approaches are on the right track. Let us assume that modern physics is indeed best interpreted as revealing that nature cannot be captured, or even best approximated, by a third-person description, and that the experiencing subject must take center stage. What would this imply for the scientific realism debate? For one thing, this would still be consistent with the existence of an external reality and even with unobservable entities such as atoms and electrons. It would also be consistent with the realist postulate to take scientific theories at “face value.” However, what it means to take science at face value would have different implications. Standardly, the claim that we should trust what the sciences tell us is understood as implying that science offers an objective description of reality.

⁸ For similar arguments, see Frauchiger & Renner, 2018, Healey, 2018, and Bong et al., 2020.

Phenomenologically construed, by contrast, one fundamental lesson taught by science is the QBist one “that reality is more than any third-person perspective can capture” (Fuchs 2017, 113).

Depending on the details, different realist commitments may pull in different directions. Let us assume, for instance, that certain no-go theorems are indeed best understood as revealing that in quantum theory there are no observer-independent facts. For the realist, this would generate a tension between the ontological commitment to an observer-independent world and the epistemological commitment that the sciences provide us with knowledge about the nature and structure of reality. If taking quantum mechanics at face value implies giving up the standard realist claim that there is an observer-independent reality, it becomes unclear what “the” realist is supposed to believe. The *scientific* realist, I propose, should put their money on what science itself seems to tell us, rather than clinging to traditional metaphysical commitments.

Such a phenomenological reconceptualization of science and its fundamental lessons would also have far-reaching implications for philosophy more generally. Traditionally, one main motivation for naturalism and externalism has been the dictum that philosophy should be modeled after the sciences. Standardly, this has been understood as requiring the purging of the first-person perspective. However, if science itself cannot be purged of the first-person perspective but instead must incorporate it, tables would be turned. The dictum that philosophy must be modeled after the sciences would then support internalist over externalist accounts (see Berghofer 2025).

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References

- Berghofer, Philipp (2017): “Transcendental Phenomenology and Unobservable Entities,” *Perspectives* 7, 1, 1-13.
- Berghofer, Philipp (2022): *The Justificatory Force of Experiences*, Cham: Springer.
- Berghofer, Philipp (2024a): “Quantum Reconstructions as Stepping Stones Toward ψ -Doxastic Interpretations?” *Foundations of Physics* 54, 1-24.
- Berghofer, Philipp (2024b): “Defending the Quantum Reconstruction Program,” *European Journal for Philosophy of Science* 14, 47, 10.1007/s13194-024-00608-2.
- Berghofer, Philipp (2025): “On the Relationship between Epistemology and Science: Synergies between Experience-First Epistemologies and Agent-Centered Interpretations of Quantum Mechanics,” *Synthese* 205, 1-18.
- Berghofer, Philipp; Goyal, Philip; and Wiltsche, Harald (2020): “Husserl, the Mathematization of Nature, and the Informational Reconstruction of Quantum Theory,” *Continental Philosophy Review* 54, 413-436.
- Berghofer, Philipp; François, Jordan; Friederich, Simon; Gomes, Henrique; Hetzroni, Guy; Maas, Axel; and René Sondenheimer (2023): *Gauge Symmetries, Symmetry Breaking, and Gauge-Invariant Approaches*, Cambridge Elements: Cambridge University Press.
- Berghofer, Philipp & Wiltsche, Harald (eds.) (2023): *Phenomenology and QBism: New Approaches to Quantum Mechanics*, Routledge.
- Berghofer, Philipp & Wiltsche, Harald (forthcoming): “Wave Function Realism and the Mathematization of Nature. A Phenomenological Perspective,” in Lars-Göran Johansson & Jan Faye (eds.): *How to Understand Quantum Mechanics – 100 Years of Ongoing Interpretation*. Springer.
- Bong, Kok-Wei; Utreras-Alarcón, Aníbal; Ghafari, Farzad; Liang, Yeong-Cherng; Tischler, Nora; Cavalcanti, Eric; Pryde, Geoff; and Wiseman, Howard (2020): “Testing the Reality of Wigner’s Friend Observations,” arXiv:1907.05607v3.
- Brukner, Časlav (2018): “No-Go Theorem for Observer-Independent Facts,” *entropy* 20, 1-10.
- Chakravartty, Anjan (2007): *A Metaphysics for Scientific Realism*, Cambridge: Cambridge University Press.
- Chakravartty, Anjan (2017): “Scientific Realism,” The Stanford Encyclopedia of Philosophy (Summer 2017 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/sum2017/entries/scientific-realism/>.
- De Caro, Mario (2020): “Hilary Putnam on Perspectivism and Naturalism,” in Ana-Maria Cretu & Michaela Massimi (eds.): *Knowledge from a Human Point of View*, Cham: Springer, 57-70.

- De Haro, Sebastian & Butterfield, Jeremy (2025): *The Philosophy and Physics of Duality*, Oxford: Oxford University Press.
- Feynman, Richard (1965): *The Character of Physical Law*, Massachusetts: The M.I.T. Press.
- Frauchiger, Daniela & Renner, Renato (2018): “Quantum Theory Cannot Consistently Describe the Use of Itself,” *Nature Communications* 9, 3711.
- French, Steven (2023): *A Phenomenological Approach to Quantum Mechanics: Cutting the Chain of Correlations*, Oxford University Press.
- Fuchs, Christopher (2017): “On Participatory Realism,” in Ian Durham & Dean Rickles (eds.): *Information and Interaction*, Cham: Springer, 113-134.
- Fuchs, Christopher (2023): “QBism, Where Next?” in P. Berghofer & H. Wiltsche (eds.): *Phenomenology and QBism: New Approaches to Quantum Mechanics*, Routledge, 78-143.
- Giere, Ronald (2006): *Scientific Perspectivism*, Chicago: The University of Chicago Press.
- Goyal, Philip (2023): “The Role of Reconstruction in the Elucidation of Quantum Theory,” in P. Berghofer & H. Wiltsche (eds.): *Phenomenology and QBism: New Approaches to Quantum Mechanics*, Routledge, 338-389.
- Hacking, Ian (1983): *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*, Cambridge University Press.
- Healey, Richard (2018): “Quantum Theory and the Limits of Objectivity,” *Foundations of Physics*, 10.1007/s10701-018-0216-6.
- Heelan, Patrick (1983): *Space-Perception and the Philosophy of Science*, Berkeley: University of California Press.
- Heidegger, M. (1967). *What Is a Thing?* South Bend: Gateway Editions.
- Heidegger, Martin (1977): *The Question of Technology and Other Essays*, New York: Garland Publishing.
- Husserl, Edmund (1960): *Cartesian Meditations*, transl. by Dorion Cairns, The Hague: Martinus Nijhoff.
- Husserl, Edmund (1970): *The Crisis of European Sciences and Transcendental Phenomenology*, transl. by David Carr, Evanston: Northwestern University Press.
- Husserl, Edmund (1973a): *Zur Phänomenologie der Intersubjektivität, Texte aus dem Nachlass, Erster Teil: 1905-1920*, Husserliana XIII, ed. by Iso Kern, Dordrecht: Martinus Nijhoff Publishers.
- Husserl, Edmund (1973b): *Ding und Raum, Vorlesungen 1907*. Husserliana XVI. Dordrecht: Martinus Nijhoff Publishers.

- Husserl, Edmund (1982): *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy, First Book*, transl. by Fred Kersten, The Hague: Martinus Nijhoff.
- Husserl, Edmund (1984): *Einleitung in die Logik und Erkenntnistheorie, Vorlesungen 1906/07*, Husserliana XXIV, ed. by Ullrich Melle, Dordrecht: Martinus Nijhoff Publishers.
- Ihde, Don (2012): *Experimental Phenomenology*, 2nd edition, Albany: SUNY Press.
- Khalili, Mahdi (2022): “From Phenomenological-hermeneutical Approaches to Realist Perspectivism,” *European Journal for Philosophy of Science* 12, 1-26.
- London, Fritz & Bauer, Edmond (1983): “The Theory of Observation in Quantum Mechanics,” in J. A. Wheeler and W. H. Zurek (eds.): *Quantum Theory and Measurement, Princeton: Princeton University Press*, 217-259.
- Madary, Michael (2017): *Visual Phenomenology*, Cambridge: The MIT Press.
- Mancosu, Paolo & Ryckman, Thomas (2005): “Geometry, Physics and Phenomenology: Four Letters of O. Becker to H. Weyl”, in V. Peckhaus (ed.): *Oskar Becker und die Philosophie der Mathematik* (pp. 153–227). München: Wilhelm Fink Verlag.
- Massimi, Michaela (2018): “Perspectivism,” in Juha Saatsi (ed.): *The Routledge Handbook of Scientific Realism*, New York: Routledge, 164-175.
- Massimi, Michela (2022): *Perspectival Realism*, New York: Oxford University Press.
- Merleau-Ponty, Maurice (1968): *The Visible and the Invisible*, Evanston: Northwestern University Press.
- Merleau-Ponty, Maurice (2002): *Phenomenology of Perception*, transl. by Colin Smith, London: Routledge.
- Merleau-Ponty, Maurice (2003): *Nature: Course Notes from the Collège de France*, Evanston: Northern University Press.
- Merleau-Ponty, Maurice (2004): *The World of Perception*, transl. by Oliver Davis. London: Routledge.
- Psillos, Stathis & Ruttkamp-Bloem, Emma (2017): “Scientific Realism: Quo vadis? Introduction: New Thinking about Scientific Realism,” *Synthese* 194, 3187-3201.
- Putnam, Hilary (1975): *Mathematics, Matter and Method*, Cambridge: Cambridge University Press.
- Ryckman, Thomas (2005): *The Reign of Relativity: Philosophy in Physics 1915-1925*, Oxford: Oxford University Press.
- Ryckman, Thomas (2020): “The Gauge Principle, Hermann Weyl, and Symbolic Construction from the ‘Purely Infinitesimal’,” in H. Wiltsche & P. Berghofer (eds.): *Phenomenological Approaches to Physics*, Synthese Library, Springer, 179-201.

- Sellars, Wilfrid (1963): *Science, Perception and Reality*, Atascadero: Ridgeview Publishing Company.
- Teller, Paul (2011): "Two Models of Truth," *Analysis* 71, 3, 465-472.
- Teller, Paul (2020): "What Is Perspectivism, and Does It Count as Realism?" in Michaela Massimi & Casey McCoy (eds.): *Understanding Perspectivism*, New York: Routledge, 49-64.
- Vallor, Shannon (2009): "The Pregnancy of the Real: A Phenomenological Defense of Experimental Realism," *Inquiry* 52, 1, 1-25.
- Van Fraassen, Bas (1980): *The Scientific Image*, New York: Oxford University Press.
- Wiltsche, Harald (2012): "What is Wrong with Husserl's Scientific Anti-Realism?" *Inquiry* 55, 2, 105-130.
- Wiltsche, Harald (2017): "Science, Realism and Correlationism. A Phenomenological Critique of Meillassoux' Argument from Ancestrality," *European Journal of Philosophy* 25, 808-832.
- Wiltsche, Harald & Berghofer, Philipp (eds.) (2020): *Phenomenological Approaches to Physics*, Synthese Library, Springer.
- Zahavi, Dan (2003): *Husserl's Phenomenology*, Stanford: Stanford University Press.
- Zahavi, Dan (2019): *Phenomenology: The Basics*, London: Routledge.