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RESEARCH ARTICLE

Observation, Experiment, and Scientific Practice

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ABSTRACT
Ian Hacking has argued that the notions of experiment and observation are distinct, not even the opposite ends of a continuum. More recently, other authors have emphasised their continuity, saying it is futile to distinguish between them as they belong on a continuum of epistemic activities. I take a middle road by suggesting that in scientific practice, experiment and observation constitute a continuum, but we can identify methodological and pragmatic aspects that define it, as well as various points on it that meaningfully delineate scientific practices. I explain the implications of the location of research projects on the continuum for scientists' epistemic responsibilities and their ethical and funding concerns.

1. Why the Distinction between Observation and Experiment Matters: Historical, Methodological, Pragmatic, and Ethical Aspects

Surprisingly, the distinction between observation and experiment is comparatively less discussed in the philosophical literature, despite its importance to the scientific community and beyond. As early as the seventeenth century, observation and experiment were seen as 'an inseparable pair' (Daston 2011, 82). But by the nineteenth century, they were understood to be essentially opposed, with the observer increasingly seen as passive and thus epistemically inferior to the experimenter (Daston 2011, 82). Daston's succinct summation of the intricate evolution of the distinction reflects the current positions of both professional scientists and the wider public:

> In the period from the early seventeenth to the mid-nineteenth century, the relationship between observation and experiment shifted not once, but several times: from rough synonyms, as in the phrase 'observations and experiments' that had become current by the early seventeenth century, to complementary and interlocking parts of a single method of inquiry throughout much of the eighteenth and early nineteenth centuries, to distinct procedures opposed as 'passive observation' and 'active experiment' by the mid-nineteenth century. (Ibid.)

This paragraph sums up the main standpoints on the relationship between these two notions that have developed in modern science. The question is why philosophers would insist on any one distinction between the two in the face of this fundamental variety. Isn't analysis of this sort a futile task, given that scientific communities, or

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even individual scientists, across different historical periods, have subscribed to different understandings of the distinction? In other words, can we say anything general at all about the distinction and still capture its various aspects?

In philosophical analyses of the distinction, there are two opposed views. First, Ian Hacking has prominently characterised it as sharp and well-defined, while avoiding the claim that observation and experiment are opposites. He states, ‘Observation and experiment are not one thing nor even opposite poles of a smooth continuum’ (Hacking 1983, 173). According to him, the notions characterise different things in scientific practice; an experiment, irrespective of how complicated it may be, always results in observation. Thus, observing a phenomenon directly is a matter of creating and manipulating that phenomenon, independently of the theories about it. Under the circumstances of phenomenon-creation by manipulating that phenomenon with an experimental apparatus, experimenters can justifiably say they observed, for example, a particle collision in an appropriate experiment. (1984, 160) If scientists can manipulate a domain of nature to such an extent that they can create a new phenomenon in a lab, a phenomenon that normally cannot be observed in nature, then they have truly observed the phenomenon. (1992, 1989, 1984) The experiment is thus a thorough manipulation, creating a new phenomenon, and observation of the phenomenon is its outcome, epistemically on a par with other more mundane scientific observations. (Hacking 1983, Ch. 10)

Second, and unlike Hacking, some authors think ‘the familiar distinction between observation and experiment … [is] an artefact of the disembodied, reconstructed character of retrospective accounts’ (Gooding 1992, 68). The distinction ‘collapses’ when we are faced with actual scientific practice as a process, and ‘Hacking’s observation versus experiment framework does not survive intact when put to the test in a range of cases of scientific experimentation’ (Malik 2017, 85). Gooding (1982, 1992) suggests we should not try to use the experimentation-as-a-process view as a cure for this biased afterthought of a distinction because observation is a process too, not simply a static result of manipulation. Thus, ‘[b]oth observation and experiment in practice involve undertaking various activities, manipulations, interventions and interpretations’ (Malik 2017, 86). They are concurrent processes constantly bleeding into each other, so ‘to (try to) distinguish between observation and experiment is futile’ (Ibid).

The general attitude in various accounts of the second view is that the distinction will resist all attempts at clear general characterisation. Observation and experiment should be understood as a continuous process that cannot be segmented in a general and meaningful way. There is no point delineating the two except perhaps in certain narrow domains; for example, distinction in Hacking’s sense, based on creating phenomena, might be useful within a narrow domain of particle physics, but applying such a distinction across scientific domains and disciplines cannot be meaningful. Authors who try to demonstrate this in their various analyses of the scientific process avoid the distinction altogether and opt for ‘the terminology [that] underlines this sense of continuousness’ (Malik 2017, 88). If we want to analyse scientific practice, the argument goes, we should leave behind the idea of the distinction as fundamental and turn to the characterisation and analysis of various ‘epistemic activities’ instead, for example, along the lines suggested by Chang (2011). Malik comments:

> Other accounts than those of Chang and Gooding have also been advanced to analyse scientific experimentation; although interestingly—but perhaps unsurprisingly … very few use Hacking's nomenclature of observation/experiment. Like Gooding and Chang, most believe that scientific experimentation should be viewed as a continuous process rather than one entailing discrete parts. (Malik 2017, 88)

This view contains a kernel of truth–as much as Hacking's, as we will see shortly. Yet emphasising the continuousness of the notions could blur the lines defining the points on the continuum by inadvertently equivocating the terms. As Daston and her coauthors (Daston and Galison 2007; Daston 2011; Daston and Lunbeck 2011) have demonstrated in their superb historical account, the distinction has played a role in delineating various features of scientific practice for scientists themselves. It has guided them and helped them articulate their reflections on their own practice.

As we will see, these two notions, observation and experiment, are still the preferred tool in debates on the epistemic status of scientific tests and instruments among scientists themselves. We would be hard pressed to fully understand many, if not most, concrete cases of scientific practice without making an effort to understand the use of these two terms and how exactly they relate to each other. The distinction has been meaningful throughout the history of practicing science. It has helped scientists and the public alike understand the process of probing natural phenomena, and any general explication of it should do the same. The fact that there is no sharp distinction between observation and experiment in scientific practices does not warrant eliminating the distinction from philosophical analysis as a vague convention. Rather, it presents us with the task of devising a more complex account than the one suggested by Hacking, for example, one that reflects the complexity of current scientific practice.

I have no intention of advancing the debate on definitions, i.e. necessary and sufficient conditions of what constitutes observation or experiment. Rather, I seek to point out how the two relate to scientific practice. No single term, be it manipulation, creation, or intervention, can define the distinction independently of the context in which it is used, and these terms help us define various points on the continuum. The fact that no one term defines the distinction and provides necessary and sufficient conditions of its use should not lead us to claim that the notions of observation and experiment can be, generally speaking, equivocated or are simply interchangeable. There may not be sharp boundaries between different areas of the continuum, but this does not mean we cannot identify those reflecting significant aspects of scientific practice.

A question we should bear in mind when analysing the distinction, along with the *methodological* question of what constitutes observation and experiment, is the following: What sort of legitimacy are scientists themselves seeking when they use the two notions? For example, why do they insist they have observed the Higgs boson[1] or the core of the Sun[2] and not merely state that they have produced certain experimental results or detected a value of a parameter? Can we offer a meaningful response to this sort of question other than simply falling back on such propositions as 'Because they created the phenomenon by intervention' or 'Because both experiment and observation are processes?' This is an important pragmatic aspect of the distinction.

The goal of my analysis is to explore the multifaceted relationship between these two notions instead of bypassing the distinction and opting for alternative terms of analysis of scientific practice. I suggest the distinction constitutes a continuum. We can identify various key points on the continuum; thus, it meaningfully and fairly precisely delineates methodological, pragmatic, and ethical aspects of scientific practice.[3] First, I argue the accessibility of the target phenomenon in scientific exploration, defined by the background knowledge about the target phenomenon, and in concert with one's ability to manipulate it (and the required instruments) constitutes the methodological aspect of the distinction. The scientists observing and experimenting always access their target phenomenon to a certain extent and perform certain manipulations involving it one way or another. It is the *extent* of accessibility and manipulability (in the context of the background knowledge) that locates the exploration on the observation/experiment continuum. Second, this methodological dimension of the distinction provides the basis for the preferred language (e.g. whether scientists prefer to label their research experiment or observation) in accord with both epistemic and non-epistemic goals of the exploration, thus shaping ethical dilemmas concerning it.

2. The Methodological Aspect: Accessibility of Target Phenomena, Background Knowledge, and Manipulability

Observation is philosophically a very loaded term, but I am primarily interested in its relationship to the notion of the experiment; it is of interest in a wider philosophical sense only to the extent necessary to shed light on the distinction. At least initially, the notion ought not to be identified with any technical, narrow meaning developed in a particular philosophical account, for example, sensory data. Historical analysis is more useful and informative as a starting point for the analysis of the observation/experiment distinction than any particular conceptual analysis. Daston clarifies a historical aspect of the notion in the following way:

> Characteristic of the emergent epistemic genre of the *observationes* was, first, an emphasis on singular events, witnessed first hand (autopsia) by a named author … ; second, a deliberate effort to separate observation from conjecture … ; and third, the creation of virtual communities of observers dispersed over time and space, who communicated and pooled their observations in letters and publications. (Daston 2011, 81)

So the scientific notion of the observation started as a first-hand (eye) witnessing of natural phenomena of interest that provided more than a conjectural insight. It slowly gained other traits that have overtaken the initial understanding, albeit with a certain important residue, as we will see shortly.

But before turning to these developments, I should note that for the purposes of analysis, the notion of phenomenon should be understood in a similarly general manner. It ought not to be identified with any specific philosophical account. Scientists are interested in phenomena as prosaic as tracing the motion of white cells' patches in our eyes or as abstract as the horizon of the visible universe.[4] It is not clear that these phenomena have anything indisputably in common other than the fact they have been the subject of scientific practice, experiments, and observations and involve the focused, cognitively selective use of senses and instruments that accompanies the practice. The parameters defining a phenomenon can thus concern various levels of description and theoretical context depending on the actual phenomenon of interest. Indeed, any account of the notion of phenomena relevant to the analysis of the distinction between observation and experimentation ought to be as general. Here, I concur with Hacking's initial characterisation: 'My use of the word "phenomenon" is like that of the physicists. It must be kept as separate as possible from the philosophers' phenomenalism, phenomenology and private, fleeting sense-data' (Hacking 1983, 222).[5]

The initial understanding of scientific observation as first-hand eye witnessing of a phenomenon still has strong intuitive appeal, and it has been connected to the notion of 'direct observation' as unmitigated insight by the senses. It is not surprising that naked-eye observations, as direct eye-witnessing of a phenomenon, or less frequently the use of other senses to directly detect a phenomenon, have historically been used as an epistemic template of sorts to assess accessibility through instrumentation. For instance, the ultimate test of an apparent patch on a wall seen through binoculars is to check the wall with our own eyes; for a long time, such tests were understandably considered inescapable and essential. Moreover, since the seventeenth century, there has been a tendency to emphasise that 'observation examined nature as presented to the senses (with or without the aid of instruments)'–widening the scope of observation as a sense-based (mainly visual) access that can be extended with instruments–'while experiment revealed hidden effects or causes' (Daston 2011, 86).

Modern science has veered away from this initial view, in two different but interrelated respects. First, and obviously, the role of the direct sensory witnessing of the target phenomenon as an end point of any observation, and thus as a template, has diminished with the use of increasingly automated instruments and computers in science.[6] In effect, scientific observation can be detached from the senses, but this does not necessarily challenge its epistemic status. The observability of a target phenomenon does not necessarily require it to be directly accessed (witnessed) by the senses. I mostly talk about the *accessibility* of target phenomena, not their observability, even though the two are practically synonymous. I opt for the notion of accessibility instead of observability to avoid the awkward sense of grading directness: 'more direct or less direct' is awkward, while 'more accessible or less accessible' is not. More importantly, the notion of accessibility is clearly neutral to human perception, including naked-eye observations, while observability has historically been connected to the human senses, especially to visual, eyewitness first-hand observations, as its primary element. And, as we will see, it is still connected to that legacy, affecting the pragmatic aspect of investigations in science. In contrast, the notion of the accessibility of target phenomena immediately suggests the decoupling of scientific observation and direct perceptive witnessing, making it easier to spot the residue of this coupling in contemporary science.

Second, the background knowledge of phenomena plays a crucial role both in defining the target phenomenon and in determining the epistemic status of its observation. Arguing in favour of this view, in his insightful and influential analysis, Shapere (1982) concludes that whether an observation is direct depends on the current state of knowledge: '[W]hat counts in science as an observation is not fully separable from the testing and justification of theories' (Shapere 1982, 492–493). To develop this point, Shapere uses the example of the detection of neutrinos taking off from the Sun's core and arriving at the detector on Earth without interruption because of neutrino's very poor reactivity. He contrasts this to photons that take billions of years to make it from the Sun's core to Earth's surface and finally into our eyes or other detectors. In the case of the former, in scientific practice, 'there are ambiguities, or at least differences, in what is said by astrophysicists to be observed: sometimes it is said to be the central core of the sun, and at other times to be the neutrinos in Davis' apparatus' (Shapere 1982, 489). Shapere further suggests that the key to disambiguating the use of the term is to understand the contrast between the two observations in terms of relevant information and knowledge:

> The key to understanding the astrophysicist's use of 'direct observation' and related terms in his talk about neutrinos coming from the sun is to be found in the contrast between the information so received and that based on the alternative available source of information about the solar core, the reception of electromagnetic information about the solar core, the reception of electromagnetic information (light-photons). (Shapere 1982, 490–1)

Thus, the 'specification of what counts as directly observed (observable), therefore of what counts as an observation, is a function of state of physical knowledge, and can change with changes in that knowledge' (Ibid., 492–493). This is an inevitable conclusion in contemporary scientific practice; whether given results count as an observation and whether we are justified in labelling it direct depend on the current background knowledge.

To go a bit further in the same direction, however, the existing background knowledge will not only determine what counts as 'direct observation'. It will also determine to what extent the target phenomenon under investigation is accessible, i.e. to what extent it is direct.[7] Observations can vary in terms of their directness, and the level of directness is a matter of degree in scientific practice determined by the background knowledge. And the *extent* of accessibility of relevant background knowledge parameters accounting for the target phenomenon that figure in the hypotheses an observer aims to test can be characterised precisely and debated by the experts. To give an example, some argue that an International Linear Collider (ILC)[8] will provide more accurate and simpler access to targeted phenomena (properties of the particles of interest) than the existing Large Hadron Collider (LHC) because of its better luminosity (the number of detected events in time *t* over a cross-section of the actual particle interactions), and vastly fewer interfering uninteresting background interactions will take place in it. Generally better access to target phenomena is the reason a group of physicists working in the field advocate constructing the ILC in the first place. In fact, debates on the epistemic value of various instruments and explorations of this sort often turn on expert estimates of phenomenon-bound accessibility.

Thus, there is no *prima facie* reason why we should not label a scientific observation that is not accessed directly by our senses but that is shaped by sophisticated background knowledge 'direct observation', that is, a target phenomenon that can be accessed directly. Yet the extent of accessibility will crucially depend on the manipulability of the phenomenon, not just on background knowledge. The authors discussing the observation/experiment distinction often focus on the notion of intervention (into the target phenomenon) to make the distinction, drawing on the view that experiments inherently involve intervention, a view rooted in history as well. But they overlook that intervention is part of a broader aspect of the distinction: namely, manipulability involves the observer and instruments as well as phenomena. In fact, phenomenon-bound accessibility (i.e. as defined by background knowledge) is typically directly tied to the extent of this comprehensive methodological aspect of manipulability, so it is hard to fully assess the extent of accessibility in a particular case without assessing the extent of manipulability. To use a very simple example, when I use the focus gear on my binoculars, I am increasing the accessibility of the phenomenon by manipulating the instrument–manipulability is not just a matter of manipulating the actual phenomenon. Yet a common perception of the observation/experiment distinction is that of an observer sitting down and observing a phenomenon that typically cannot be easily reached, as it is either at some distance or exceptionally small, as opposed to the experimenter who is actively involved with the phenomenon, controlling it or intervening with it, taking it apart, and so on. This distinction has its roots in seventeenth century science:

> By the late seventeenth century, the [scientists] were drawing distinctions between experiments and observations on the basis of whether one intervened in the course of nature to produce an effect or studied effects as they occurred in the course of nature. As Leibniz stated, 'there are certain experiments that would be better called observations, in which one considers rather than produces the work.' (Daston 2011, 86)

Observation became juxtaposed to other, more complex modes of inquiry; 'the most important of these was "experiment," whose meaning shifted from the broad and heterogeneous sense of *experimentum* as recipe, trial, or just common experience to a concertedly artificial manipulation, often using special instruments and designed to probe hidden causes' (Daston 2011, 82).

This understanding of the distinction has played a crucial role in characterising and understanding certain scientific practices and is still around. But if we want to understand the entire observation/experiment continuum and where that particular understanding of the distinction is situated on it, we need to take a step back. In fact, manipulation in the most general sense should be understood as leveraging the observer and/or instrument, i.e. the instrument/observer interface, on the one hand, and the phenomenon, on the other, not as manipulating the phenomenon alone. This aspect concerns the extent of manipulation of each phenomenon and the points on the continuum designated in light of that extent.

The line between observation and experiment can be drawn only in terms of the extent of manipulation, not as an essential characteristic of experiment alone. Thus, there is always at least cognitive manipulation taking place, in terms of the selection of particular aspects of the phenomenon of interest. At a very basic level of visual observation, there is also a manipulation of eye movements, the nature of which is crucial for proper accessibility of the phenomenon. A long history of observational astronomy tells us how complex it is to use the naked eye as an instrument or as an extension of an instrument (one-eye use, adjustment to light conditions, adequate squinting, looking slightly away from focal points, etc.). In fact, understanding the eye and its physical and optical properties as an intricate observational instrument is concurrent with the beginnings of modern scientific observation and experiment. Thus, even in the naked-eye observational testing of twinkling stars and non-twinkling planets, a substantial extent of manipulability is required.

The instrument (eye) is a well-trained organ of our bodies used in concert with our everyday cognitive skills. It is a basic but not irreplaceable instrument for accessing targeted phenomena (i.e. for a scientific observation, even a direct one). As I have pointed out, scientific observations are not necessarily tied to our bodily organs at all. Thus, the examination of many natural phenomena of interest to scientists today, including celestial phenomena, requires instruments that do not involve the use of eye manipulations exclusively, if at all. For instance, instruments have, by and large, successfully replaced and far exceeded all the functions of the eye as a key instrument for observing celestial phenomena of interest. A telescope vastly increases accessibility into many phenomena, including the twinkling of the stars, thanks to a substantially more complex level of manipulation. Automated telescopes scan the sky, pick interesting objects to record, and deliver results in the form of a diagram or a table in any desired quantitative manner or, if preferred, as a visual representation. Similarly, physicists feed data into a particle collider and receive results *via* computer. And, theoretically speaking, it is conceivable that we perform an experiment using automatically built and maintained equipment without ever seeing any piece of it.

Extremely automated instruments aside, the use of instruments often involves manipulations of the entire body integral to the operation of the instruments. In such a case, the scientist is appropriately manipulating the apparatus along with her body when she is focusing an instrument's lenses or manipulating its spatial properties, for instance, positioning a telescope in a location with low light pollution and in a stable section of Earth's atmosphere, or when she is locating multiple instruments to be used in concert at various locations on Earth (e.g. LIGO or a network of telescopes). She can also manipulate her observational timing, for instance, by waiting for certain aspects of the phenomenon to appear, such as waiting to observe various sides of a planet at different times. And she can manipulate her location, along with the temporal properties of the phenomenon, that is, the spatial component of its observational situation, in an elaborate way that improves or even enables the accessibility of a desired parameter. Thus, when measuring parallax, she repeats the measurement of the position of a celestial object at two different points in Earth's orbit in order to measure the angle and determine the distance to the object, knowing the radius of Earth's orbit. In effect, she manipulates both spatial and temporal properties. These are negligible distances and time scales when compared to the scale of the phenomenon itself, its size, and distance from the observer; yet they are crucial in terms of accessibility.

Moreover, the repetition of observations is a particular kind of manipulation of the temporal properties of the observer-phenomenon relationship to the advantage of the observer. Tycho Brahe was among the first, if not first to practice this, with dramatic results when Kepler utilised his data (Daston 2011, 96).

The test in cases like these still looks very much like a passive observation of, for example, an extremely large and very distant object when compared to the size of the observer–we are still firmly at the observer's end in terms of manipulation and thus at the far 'observation' end of the observation/experiment continuum because of the low manipulability (Figure 1). Yet these manipulations at the observer's end, as negligible as they may seem when compared to the full-scale manipulation leveraged towards the phenomenon and thus found at the experimentation end of the continuum, are crucial for the success of observational tests, as they improve the accessibility of desired aspects of the phenomenon.

It is worth noting here that a common approach to understanding scientific methods and knowledge in terms of causation and conditional causal statements focuses on the analysis of the manipulation of relevant phenomena in scientific research (Woodward

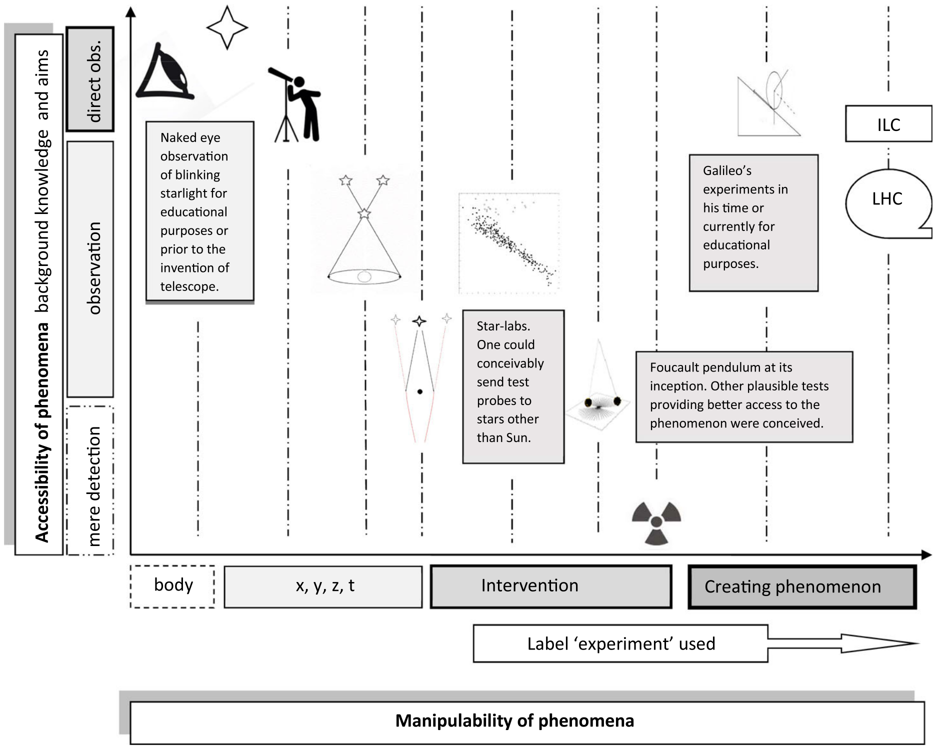

Figure 1. The diagram is a rough suggestion about where various cases are located on the continuum. The final judgment on the accessibility of current exploratory and past projects along the accessibility and manipulability axes belongs to the expert scientists and historians respectively.

2005). In fact, it characterises scientific knowledge as deliberate methodical causal manipulation. Now, while manipulation characterises every single observation one way or another, as should seem obvious from the argumentation so far, this does not necessarily mean that a particular cut-off point for manipulation in a more substantial sense, in line with this causal approach to scientific method, does not exist. The causal analysis of manipulation seems to align with the notion of manipulation as intervention. But having said that, even if this is the case, understanding the seemingly less substantial instances of manipulation related, for instance, to the calibration of instruments deserve much more attention from those studying the scientific method in terms of causal manipulation.

The notion of experiment is certainly identified by the heightened substantial extent of manipulability in investigations. There seems to be a point on the continuum where manipulation reaches a certain level that makes us comfortable labelling an investigation 'experiment' (Figure 1). Generalising a rigid distinction between observations as essentially static and experiments as interventions into phenomena is in danger of making a particular arbitrary cut-off line seem essential at some point on the continuum. We should bear in mind that it is really a matter of degree; what we call a full-scale 'experiment' on the one hand, and a naked-eye 'observation' on the other are points at the far ends of the continuum in terms of their respective levels of manipulation. Actually, the cases typically not labelled experiments but (mere) observations–towards one end of the continuum (Figure 1)–are still characterised by various levels of manipulability of the observer and instruments, while the full-scale experimentation end of the continuum is characterised by the substantial manipulation of the phenomenon.

Intervention is a threshold area on the continuum (Figure 1). Here, manipulation is leveraged more towards the phenomenon and thus edges closer to the full-scale experiment end of the continuum. In this area, various techniques differ incrementally in the extent of their intervention with the phenomenon. On the one hand, splicing genes or swinging a pendulum fixed on a church ceiling is close to the far end of the intervention threshold. On the other hand, gravitational lensing is an intervention with an instrument surrogate, making it an example of initial manipulation on the instrument side, firmly at the observer's end, yet much closer to the intervention area than, say, regularly observing the galaxy with a telescope. This is a use of a natural phenomenon as an instrument-surrogate. It conveniently bends light that is emitted by an object and obscures the object to the observer; the light 'goes around' the object as the surrogate instrument's gravitational pull bends it. The observer does not really produce an instrument that intervenes with the phenomenon. Rather, the observer uses a naturally occurring phenomenon as a surrogate of an intervention and thus reveals the relevant phenomenon's aspects, for example, the spectrum of light emitted. There is no need to draw a particularly sharp line between human-made intervention and a convenient intervention using a natural surrogate with a similar outcome; observation of the corona during the Moon's eclipse of the Sun using an artificial coronagraph is a case in point.

An equally substantial manipulation effect can be fashioned by intervening with a single phenomenon, or alternatively, by observing multiple phenomena of interest under varying conditions while comparing resulting differences. To give an example, in terms of deeper manipulation of initial conditions to see how varying these will change certain aspects of the phenomenon, we can use stars as surrogate laboratories. Stars with different masses will evolve differently and emit light that can be detected; these natural furnaces will produce a surrogate process under varying conditions without requiring a human made laboratory.

This manipulation by appropriate object selection is widespread in life and the social sciences. In such cases, an observer uses nature or society as a convenient surrogate laboratory that produces a desired interaction in a relevant phenomenon on a massive scale: surrogate labs can even conveniently fix certain parameters or vary other parameters of interest. The observer does not actively manipulate the phenomenon. She makes a seemingly negligible manipulation on her end; therefore, she can opt to stick with the label of observation in her research, emphasising relatively passive access to the targeted phenomenon. This has pragmatic and ethical implications, as we will see in the next section. But by such comparatively negligible manipulations, i.e. pointing the telescope in the right direction and using convenient natural activities, she interfaces with a natural process that effectively becomes her giant laboratory, fixing and varying the desired parameters for her. Yet tests of this sort are sometimes labelled experiments: this label typically aims to emphasise the crucial scope of manipulability of the phenomenon, while the label observation typically designates cases of lower manipulability. How scientists characterise their work will depend on which aspect they wish to emphasise. This is shaped by the aims of their research, with possible consequences on the ethics of the research and funding decisions. But before I turn to the pragmatic aspects of the continuum, let me finalise the analysis of the methodological aspect.

Beaumont's (1833) test, as discussed in the literature (Hacking 1983; Malik 2017), is located even further towards the experimental end than the use of surrogate instruments because of the scale of the intervention; the intervention took advantage of a natural occurrence but was partially humanly designed. More specifically, Beaumont performed an operation that inverted the stomach of an injured soldier, so fluids could be directly applied to test various hypotheses about gut metabolism. Malik considers this an illustrative example of the conflation of observation and experiment, stating that both 'in vivo and in vitro work needs intervention (of some kind) to be satisfactorily completed making it impossible to distinguish (in any consistent and coherent way) between what should be observation and what experiment' (2017, 87). Malik's conclusion is hardly helpful, as it misses meaningful delineations of practices that parse the areas of the continuum.[9] Beaumont's test may indeed be located in an area of the continuum between full-scale experiment and simple observation characterised by low manipulation, but it is not the same as, for instance, rolling a ball in incline experiments where every parameter can be directly manipulated and, in fact, created by the experimenter. Nor can we locate it with the observations that determine the parallax because of its substantially different manipulability. It is obviously somewhere between the two. To compare the epistemic scope of experiments and to characterise aspects of experiments located in the same area of the continuum, we need to describe and understand differences and terms of intervention–that is, the extent of manipulation.

Finally, on the far experimental end of the continuum, we find experiments such as, for example, those with inclines in mechanics, where we can adjust the angle of the incline, the mass of the ball, and friction conditions. Simply stated, we can manipulate, intervene in, and control in various ways all of the desired parameters defining relevant aspects of the phenomenon. In fact, these experiments go beyond this; the phenomenon is entirely conceived, designed, and maintained by the experimenter. This is the feature of manipulation that Hacking pronounces a defining feature of experimentation and Bacon characterises as 'artificial' (Daston 2011, 86). Experiments in early particle physics belong to this category as well (e.g. experiments with Compton scattering). The experiments in High Energy Physics particle colliders also belong to the area where initial and boundary conditions can be controlled, and the phenomenon is created *ab novo*.[10] In all such cases, the resulting observations are guided by a thorough manipulation of the phenomenon–that is precisely what the label 'experiment' is emphasising in these cases. It is replaced with the notion of observation only for pragmatic purposes to which we turn shortly, that is, when scientists wish to emphasise that the results of a particle collider experiment are genuine observations; i.e. access to the target phenomenon is as genuine as that of naked-eye low-manipulation observation of starlight. Such observations involve very elaborate manipulations; that is what makes them experimentally obtained observations. But they can be quite direct: the phenomenon is as accessible with the apparatus as a targeted twinkling star is accessible with the naked eye, another appropriately manipulated apparatus.

Thus, in general, the accessibility of the phenomenon being tested ranges from mere detection to direct observation. The manipulability gradation starts with the manipulation of the eye as an instrument, moves to the manipulation of spatial properties and timing, and with increasing intervention in the phenomenon, ends with the full-fledged creation of the phenomenon. And manipulations characterised as experiments can range from those that, if not mere detections of a single property of the phenomenon (e.g. the use of the Geiger counter), are certainly not high on the accessibility axis up to observations of varying accessibility. This is the crux of the methodological aspect of the observation/experiment continuum. Now, how robust the results of investigation can be depends on the extent of accessibility of relevant parameters observed and on the extent of manipulability. In turn, the tractability of a target phenomenon will depend on this robustness. Ideally, investigation into a target phenomenon will access and manipulate it across the physical scales: it will probe all the properties of the phenomenon at any given scale (it can 'surround' the event, as it were). Theoretically speaking, a phenomenon targeted with contemporary instruments can be highly accessible, or even as accessible as, the twinkling of the stars and non-twinkling of the planets are to the naked eye–if a required level of manipulability is reached. For instance, even the Higgs scalar field, one of the hardest physical phenomena to discover experimentally, is *potentially* (although probably not in the foreseeable future) maximally accessible with the use of adequate particle colliders and detectors, that is, given the background knowledge defining the phenomenon and the level of manipulability and instrumentation required to enable it. This will certainly involve high levels of manipulation, far exceeding the manipulation needed in naked-eye observational astronomy simply because of the nature of the target phenomenon–an ambitious target phenomenon will often require vast extents of manipulation of phenomena and instrumentation. Thus, the fact that we need the Large Hadron Collider or a future superior instrument built to access the Higgs scalar field because the naked-eye as an instrument simply can't do it does not necessarily make the result less of an observation. It does not necessarily make it any less accessible than our naked-eye observation of twinkling stars either. We just need an instrument other than the naked eye, involving much more complex manipulations (that we weren't born with or habituated into while growing up) to probe the targeted phenomenon. Nor is an observation of twinkling stars and non-twinkling planets with our own eyes devoid of subtle manipulations. We would be hard pressed to draw an essential distinction between these two activities. Both yield genuine observations, and both require manipulations, albeit of substantially different extent and nature. If we manage to achieve the levels of manipulation required by the state of the art background knowledge defining the basic parameters of a target phenomenon, the target phenomenon is as directly accessed as any.[11]

Thus, the accessibility of the target phenomenon cannot be simply reduced to how readymade the investigated phenomenon is, because observational tools and techniques, as well as the background knowledge on them and the target phenomenon, are always involved in these assessments. If we 'measured' accessibility in every case having in mind eye-witnessing as the final goal, we could perhaps reduce it that way. Yet for the reasons we have given, such a reduction became largely irrelevant a long time ago with the introduction of new techniques and instruments. Instead, our observational tools and required manipulations only realise our epistemic aims in as much *as they are delineated by the background knowledge*. In such a situation, there is no simple template like eye-witnessing, against which we can assess accessibility. A higher level of accessibility is obviously epistemically advantageous, generally speaking, but this judgement must be always assessed against the background knowledge, as well as often complex aims of research to which we turn shortly. (We will see in the next section, for instance, that studying a live specimen limits the epistemic advantage of more direct manipulation of the target.)

Given this, we can try to characterise the extent of accessibility in some particular cases depending on what sort of parameters figure in theories and models of the phenomenon which scientists target; i.e. what exactly these phenomena are and to what extent they need to be and can be manipulated, according to the state of the art background knowledge. Early particle physics and the physics preceding it from the 19th to the beginning of the twentieth century belonged to a category of highly accessible phenomena, because light and matter are all around us at the desired energy scale specified by the physical theory of the time. It took ingenuity to construct adequate instrumentation, but it addressed the desired parameters at an appropriate and highly accessible physical level. The same goes for theories of electromagnetism and solid state physics.

Physicists are looking for deeper constituents of matter in High Energy Physics than they were in early particle physics, so the accessibility of target phenomena seems more moderate than in the previous examples; the energy scales as determined by current physical theories (Quantum electro dynamic, Quantum field theory, standard model of particle physics) are not as readily available, or more precisely, as easily generated. Moreover, physicists can access these constituents only fairly indirectly, via signatures of other particles (photons or electrons), the activity of which can be detected by measuring charge potentials. In fact, it took four decades before physicists could access anything close to the desired physical level required to test for the existence of the Higgs scalar field. This certainly seems a less accessible phenomenon than lines of force in the electromagnetic field or electron-photon collisions, given the contemporaneous physical theory accounting for the target phenomena.

In many cases in astrophysics, we are dealing with moderate accessibility as well; properties of nuclei or any processes taking place within stars or galaxies are subject to theoretical inferences from more directly accessible radiation phenomena on their surface. Shapere focused on the opposite case in astrophysics (inert neutrinos leaving the Sun's core) to make his point about direct observation, but the neutrinos flying unobstructed to us from the Sun's core are an exception, not the rule. Not all cutting-edge observations are direct; far from it.

In sub-fields of physics like cosmology, we are dealing with low accessibility for two different reasons. First, it is a deeply historical science, so only the remnants of the processes of interest are accessible, and, unlike most phenomena in astrophysics, we have only one universe we can observe and are interested in accessing, in contrast to myriad available stars and galaxies in various conditions in astrophysics. Second, our particular place and time in the universe constrains the accessibility of the desired targeted parameters much more than in the previously mentioned fields of physics, as we do not know with certainty where exactly we are located, and only a certain slice of the universe is accessible to us.

3. From Epistemic Aims to Pragmatic and Ethical Aspects of the Distinction

A major point that is not typically a focus of analyses seeking to clarify the methodological points discussed so far is that the aim of investigation contributes to delineating the target phenomenon by delineating the scope of relevant background knowledge and thus the extent of required manipulability of the target phenomenon. If, for instance, we are observing twinkling of starlight for educational purposes or out of curiosity, the naked eye will provide sufficient accessibility: a naked-eye observation distinguishing the twinkling of stars from non-twinkling planets in the visible part of the radiation spectrum is a test via fully accessible phenomena. And the background knowledge of the parameters defining the target phenomenon is simple in this case; it comprises understanding the concept of the frequency of light-source twinkling and the distinction between the point-like stars and planetary disks. Thus, it is an example of what either a scientist or a lay-person could justifiably call 'direct observation'. In cases of this sort, timidly defined aims render easy access to target phenomena.

The aims of observations and experiments can be different, from broadly epistemic–ranging from mere curiosity to elaborate tests of hypotheses–to non-epistemic, such as for training purposes. As we have seen, the direct eye-witnessing or the naked-eye observations of natural phenomena without additional instruments on the one hand and full-fledged experiments on the other are located at opposite ends of the manipulability axis of the observation-experiment continuum. But given their respective aims, both can provide high accessibility to the target phenomenon; i.e. both are very high on the (phenomenon-bound) accessibility axis. It is the difference in the scale of manipulation that leads us to label them differently. Moreover, the aims of observations and experiments and the background knowledge of the target phenomena are inseparable; the aim will delineate how much of the available background knowledge is relevant for the purpose and will provide sufficient accessibility. Thus, for instance, before the invention of the telescope, taking all the available knowledge (the then-known relevant parameters) into account, as well as the instrumentation with which the phenomenon could be observed at the time, what is now considered a simple educational observation of twinkling stars and non-twinkling planets would be justifiably deemed a direct observation, even having the cutting-edge aims in mind (Figure 1). Now, if we look only at the cases of observations and experiments driven by cutting-edge epistemic aims, rather than training aims or mere curiosity, the scale of the accessibility of phenomena across these scientific investigations will vary greatly. If our aims are very ambitious, then pretty much the entire body of relevant background knowledge will be employed in defining the parameters of the target phenomenon (e.g. in observations related to the core of the Sun), and the full extent of the required manipulation must be met.

It is important to note that the high manipulability at one end of the continuum is not always epistemically superior to low-manipulability observations, even when it comes to cutting-edge epistemic aims. Given that the epistemic aims are a key determining factor in investigation, our intention can be to observe a particular parameter defining a phenomenon without manipulating it. This is typical, for instance, of field work, such as observing animals in the wild. Observing chimps in their natural environment without much manipulation is as direct an observation as it gets, as the phenomenon aimed at is simply the observation of behaviour in the wild and requires limited manipulation. We could cut open a chimp, but resulting observations would not be relevant to the phenomenon of interest (nor in most cases ethically permissible). An additional level of manipulation, like adding a radio transmitter to specimens, might improve accessibility, but any more direct intervention would just not do, given the aims. It is important to realise that although experimenting, as opposed to merely observing, involves more thorough manipulation of the phenomenon, it may be epistemically inferior or even detrimental to our knowledge of the desired phenomenon, given the aims of the investigation. The accessibility is always determined by and the epistemic standing of experiments and observations always crucially depends on the aims of research, in concert with the required extent of manipulability and relevant background knowledge.

Another pragmatic aspect of the observation/experiment distinction is the characterisation, or simply put, the *labeling* of the investigation at stake. Characterising or labelling the probing of a phenomenon as an experiment or as an observation locates the probing somewhere between the two extreme points along both axes (of accessibility and manipulability) and is a matter of *emphasizing* its continuity with either the closer or the farther ends of the continuum. The language used is always a matter of emphasis and is defined by the methodological aspects of investigation; in other words, the pragmatic aspect of the observation/experiment delineation language is framed by the methodological aspects of the distinction. Whether a target phenomenon is characterised as observed and to what extent, or whether its properties are, for instance, labelled as merely detected, or whether it is called an experiment, it is first assessed along the axes of accessibility and manipulability and then labelled accordingly, with all the accompanying epistemic and practical implications.

Typically, we would be reluctant to call the observation of a star with the naked eye an experiment, although we would not be unjustified in doing so. We tend not to label this an experiment because the level of manipulability is very low compared to other observations. Yet we are justified calling it an experiment if we wish to emphasise the manner in which we use our eye in observations–by training it and manipulating the observational situation using varying spatial and temporal properties. As I have noted, throughout the centuries of scientific practice, experiment has become the label for cases of higher manipulability. This is so that we may emphasise the manipulability aspect of tests, not because a naked-eye observation is not manipulation. And when we call something an experiment, we do so because we want to emphasise that the manipulation in that particular instance, although it may be on a lower scale, is nonetheless crucial and thus epistemically continuous with tests like rolling balls on inclines and particle collider experiments that we typically label experiments.

Along the same lines, physicists tend to call LHC tests experiments, rather than observations, because of the extreme levels of manipulation with physical matter taking place in them. But as I argued earlier, they can justifiably state that the Higgs boson was observed, and observed directly, in order to emphasise continuity with naked-eye or any other observations involving manipulation with little or no instrumentation other than the human eye and thus emphasise epistemic continuity or scaling along the accessibility of the target phenomenon's axis. Thus, we typically call observations of highly manipulated phenomena 'experiments' to emphasise the extent of manipulation, while we label the results of such elaborate experimental manipulations 'observations' to emphasise the extent of the access. And we are as inclined to label results from the latest automated network of telescopes an 'observation' as we are to call the latest results of the LHC an 'experiment', but this labelling has to do with the nature and the extent of manipulation in the respective explorations, not the extent of accessibility.

Yet it is not simply scaling the observation/experiment continuum in combination with the traditionally identified points on it that determines what exact aspect of the continuum we emphasise in a particular case. These various aspects of observation and experimentation, the estimates of accessibility of phenomena, and the characterisations of the investigations in these terms often have further practical implications. As we have seen, given the cutting-edge epistemic aims of today's scientists, who are not interested only in training or satisfying casual curiosity, and their best knowledge of the parameters defining the target phenomena, accessibility varies, sometimes greatly. But the way scientists qualify accessibility, starting with the methodological assessment, has profound consequences. The pragmatic aspect is interrelated with the aims of research, the background knowledge, and the required manipulability; this is why it matters to scientists how *exactly* they characterise the target phenomena and their aims. This can matter profoundly in terms of understanding of what exactly could be and has been achieved in their investigations, with further practical implications (e.g. those concerning funding). At times, they may seamlessly agree on labelling (e.g. it is clear that physicists 'observed' Higgs boson as they 'experimented' with it), but in other instances, they will have profound disagreements.

For instance, astronomers discussing the epistemic status of the LIGO project[12] on detecting gravitational waves have utilised a distinction between observation and detection (Saulson 1994; Elder 2020). Some astrophysicists argue the LIGO setup is not truly an observatory, as this notion is applied to astronomical observatories sensitive to the electromagnetic field. In effect, they advocate the detection of light as the criterion for genuine observation as opposed to the detection of gravitational waves as mere non-observational detection, the instrument for which does not merit the label 'observatory'. In contrast, for decades, scientists working to improve the sensitivity of LIGO considered it observatory, as much so as any regular astrophysical project working with electromagnetic radiation, since at some point of development, they started using appropriate techniques to spatially locate the source of gravitational waves. The argument was that LIGO does not merely detect properties of the waves, i.e. the emitting of the gravitational wave from a source with certain physical properties. In this view, raising sensitivity to the point of detecting the location of the source is the threshold for genuine observation.

This issue played a role in the struggle to realise the project and in public perceptions of it (Allain 2016; Overbye 2019). The views were articulated along two opposed traditional lines of methodological reflection on the nature of scientific observation. Some insisted the electromagnetic spectrum was a necessary foundation of genuine observation of a phenomenon, basically extending the traditional visual notion of observation to the entire electromagnetic field as a new template. Others insisted that a more general accessibility of the target phenomenon, including locating the source, should define observation. The characterisation, the criteria, and the arguments used in the debate have consequences in terms of the epistemic standing of the results delivered by LIGO, and this, in turn, affects how funding agencies perceive the goals and the results of the project. This debate and the dilemmas it raises add a new layer to the long history of reflecting on the notion of observation in science and hinge on the assessment of accessibility of the target phenomenon and its merits.

The way scientists characterise their research on the phenomenon of interest–whether they label it experiment or observation, and what aspects of the continuum they emphasise–has consequences for the perception of the research by funding agencies, political bodies, or a wider public to which these agencies report. It makes a difference whether

LIGO merely detects certain properties of largely mysterious objects, analogously to Geiger counter measurements sampling a surrounding, or extensively observes and locates a phenomenon like a regular telescope does. Making the latter case may be a crucial step in convincing funding agencies of the project's importance.

Moreover, the extent of manipulability and accessibility of a target phenomenon shapes the attitude of observers and experimenters; i.e. it undergirds their epistemic responsibility. Generally speaking, the scientist is justified, and even obliged, to treat her knowledge of a phenomenon as tentative if both accessibility and manipulability of the target phenomenon are very low. And generally speaking, she is justified in treating available knowledge as much more reliable if both accessibility and manipulability are exceedingly high. Yet this only holds for cases at the far ends of the continuum. The level of manipulability, for instance, is inherently related to the way the epistemic goal is defined and, thus, the way the target phenomenon is selected. What exactly can be accessed and to what extent it is inherently related to manipulating the phenomenon range widely–from observing chimps in the wild to observing electrons in a piece of metal. And it would be hard to even formulate the epistemic goal and the phenomenon in these two cases, or any other, without delineating them by specifying the manipulation of the target phenomena involved, let alone assesses their epistemic payoffs. Accessibility and manipulability are intrinsically context-dependent in this sense, and this is why we must judge accessibility with the background knowledge in mind, as well as the intricacy of the aims of the particular research.

As the observation/experiment continuum is both wide and fine grained, determining the epistemic attitude and responsibility with respect to a certain point on the continuum will rarely be all that simple and will require substantial reflection. For instance, in the case of social and natural (e.g. cosmology or natural history) historical sciences, the initial conditions are out of reach. In cosmology, only a narrow set of parameters is available within a narrow space–time slice in the evolution of the universe, while in archeology, only a slice in the evolution of humanity (i.e. archeological record) is available. In fact, the historical aspect of the field's inquiry limits it to low accessibility and manipulability: there is a low level of manipulability across historical or evolutionary (e.g. in biology) stages and very limited access to relevant parameters. This applies to other historical sciences as well.[13]

Now, low accessibility and manipulability will typically provide a wide space for constructing alternative accounts of a phenomenon, as relevant parameters are either testable with low manipulability or not accessible at all. Thus, they can be conveniently slotted into various, often opposed, theoretical frameworks pending increased robustness of testability (in some cases, this is postponed indefinitely). This can result in substantial variations on what parameters constitute a fundamental theory and substantial variations within the fundamental theory candidates. In other words, low accessibility and manipulability facilitate the proliferation of alternatives.[14]

The tests belonging to that tentative area of the continuum require particularly subtle epistemic judgement. It crucially matters to what extent scientists take into account where exactly on the observation/experiment (accessibility/manipulability) continuum relevant tests belong. In such cases, it is epistemically both responsible and advantageous to avoid treating failed alternative interpretations as we would treat falsified alternatives in cases of high manipulability and accessibility. They can rarely be justifiably deemed to be straightforwardly refuted. Rather, these alternative accounts are a resource for approaches that can potentially but realistically be revised and revived. They can be treated as initial dips into a wider pool of possible alternatives. This sort of attitude is an epistemic duty, given the location on the continuum: alternative accounts of a phenomenon ought to be thoroughly explored.

Finally, the ethical nature of the continuum is framed by its methodological dimension. On the one hand, we find *experimenting* with people *prima facie* suspect, except in very special circumstances, because we find manipulating people, i.e. intervening in their behaviour without their knowledge and consent, morally unacceptable. On the other hand, we find *observing* human behaviour acceptable and desirable, except when observing humans contains some elements of *manipulation* and lacks their consent. This distinction, crucial to the ethics of research, hinges on the extent of the manipulability of relevant phenomena, and determining the extent of intervention with human subjects is co-extensive with the ethical ramifications of research. What exact level of manipulating a sentient being is ethically permissible? Generally speaking, in terms of ethical norms and epistemic scope, scientists opt for labelling and treating such research as experiments if they wish to emphasise the intervention aspect (performed via the strategy of using surrogate natural phenomena).

We have only scratched the surface of the ethical dimension of the observation/experiment continuum and its interrelation with the methodological aspect, and this is likely the aspect most in need of further analysis.

Notes

1. Observation is a preferred technical term in High Energy Physics in this context; even a casual look at publications coming out of ATLAS and CMS collaborations indicates this.
2. Shapere (1982) made this example a focus of his analysis in the context of the notion of direct observation. I discuss his argument in due course.
3. I should note that scientists are only beginning to learn the various ways computer simulations can be used and to discover their methodological ramifications, so it is too early to devise a definitive and thorough epistemic account. The observation/experiment distinction has a much longer history.
4. We could stretch the notion of 'phenomenon' to include, for example, early universe objects only very indirectly accessible to us. In that sense, the Big Bang is a phenomenon we can access indirectly.
5. For a recent discussion of the notion of phenomena in science, see Colaço (2020). Note that phenomena can be understood in a richer sense, as effects recorded as data (Bogen and Woodward 1988).
6. The domain of visual observation as a template has been extended to the electromagnetic domain of phenomena with clear consequences for the methodological and also for the pragmatic aspects of certain explorations.
7. Although I will not discuss the point here, I should note that estimates of accessibility as a key for distinguishing observation and experiments are neutral to the question of theory-ladenness.
8. See https://linearcollider.org.
9. We are compelled to stop delineating these practices in terms of the distinction between observation and experiment only if we predicate the delineation on seeking necessary and sufficient conditions for defining them.
10. These experiments work with less accessible, less directly detected phenomena if we think of them in terms of comparative accessibility or even in terms of accessibility potentially

enabled by yet non-existent colliders with better precision as we will see shortly. They can be also turned into surrogate labs analogous to star labs when we comb through vast data with various hypotheses – in effect, retrodicting rather than predicting.

11. Although I cannot go into detail here, this view stands in stark contrast to the one pursued by advocates of traditional empiricism. Van Fraassen (1977) famously argued that the target phenomena in scientific investigations are essentially unobservable. If the accessibility of seemingly exotic physical phenomena could be and, given the right conditions in actual investigations, *is* on a par with naked-eye observations, then the everyday unaided use of the senses to observe phenomena does not have a special, grounding epistemic status. This status is achieved through the deepening interface between background knowledge and improved manipulability.
12. LIGO stands for Laser Interferometer Gravitational-Wave Observatory.
13. See Currie (2018) on the methodological specificities of the historical sciences, especially on the accessibility of targeted phenomena.
14. This is typically the case with scientific quests for origins, such as the origin of the universe, origin of life, or origin of agriculture.

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