MEASUREMENT, REPRESENTATION AND THE SCIENTIFIC CONCEPT OF OBSERVATION

George Borg

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1. Introduction

In this paper I will examine an analysis of the concept of observation offered by Dudley Shapere in his 1982 article on “The Concept of Observation in Science and Philosophy.” In this article, Shapere attempts to defend a concept of observation closely based on contemporary scientific practice while at the same time defending a traditional form of empiricism (albeit with revisions), according to which all knowledge is based on experience. I argue that though his analysis of observation in contemporary science is close to the mark, it needs to be modified to take into account what I will describe as a representational function of measurement. If this modification is granted, however, I argue that one cannot consistently maintain both the revised concept of observation and traditional empiricism.

This paper is organized as follows. In section 2, I describe Shapere’s analysis of scientific observation and how it contrasts with traditional philosophical conceptions, namely by eliminating sense-perception from playing any necessary observational role. Section 3 examines measurement in somewhat more detail than Shapere does. I argue that representation is essential for generating information from the phenomenon being measured. In section 4, I ask whether Shapere’s analysis is compatible with the representational function described in section 3. I argue that it is not, but can be modified to accommodate this function. In section 5, I argue that the modified analysis is incompatible with the empiricism Shapere seeks to defend. Nevertheless, I conclude, there is a way of saving an important feature of that empiricism that is compatible with the modified analysis.

2. Taking the human out of observation

According to Shapere, the philosophical concept of observation has traditionally had a dual aspect. On the one hand, philosophers tend to conceive of observation as a special kind of perception, for example as ordinary perception to which has been added an extra ingredient of focused attention.[1] On the other hand, the philosopher's use of 'observation' also has an epistemic aspect, namely the evidential role observation is supposed to play in justifying beliefs: observation is used to acquire evidence for beliefs. Shapere has in mind a traditional sort of empiricist philosopher, according to whom all knowledge "rests on experience." On this view, experience affords observational support for beliefs, and in order for a belief to count as knowledge, it must have such support. Traditionally, writes Shapere, philosophers have largely identified these two aspects of observation, by supposing that the question of how observations support beliefs is identical to the question of how *perception* supports them.

Though Shapere wants to defend traditional empiricism, he rejects the identification of the two aspects of observation. The reason is that according to Shapere, science has come more and more to exclude sense-perception as much as possible from playing a role in the acquisition of observational evidence.[2] He bases this claim on a study of the use of the term 'observation' in contemporary physics, in particular in discussions of solar neutrino experiments designed to provide information about conditions in the core of the sun or other stars. He reports many instances of physicists talking of "directly observing" the interior of the sun by capturing neutrinos in large quantities of cleaning fluid, and inferring various properties of the sun's core from them. For example, one physicist writes that "there is no way known other than by neutrinos to see into a stellar interior" whereas another claims that "neutrinos present the only way of directly observing" the hot stellar core.

In these cases, physicists use 'direct observation' in circumstances where direct *perception* is clearly impossible. We therefore have a choice, says Shapere. We can dismiss such talk as loose, metaphorical, sloppy or whatever and hold that the proper use of 'observation' is the one philosophers accept, involving sense-perception. Or we can take such talk seriously, as

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[1] Shapere (1982), p. 507.
[2] Shapere (1982), p. 508.

perhaps indicating that the relation between observation and sense-perception in science is not as self-evident as philosophers are wont to think.

Shapere opts for the latter course, and argues that theses scientists are using 'direct observation' in a sense that is appropriate, yet quite different from the way philosophers would use the term. He offers the following analysis of 'direct observation:'

> *x* is directly observed (observable) if:
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> 1. Information is received (can be received) by an appropriate receptor; and
> 2. That information is (can be) transmitted directly, i.e., without interference, to the receptor from the entity *x* (which is the source of the information).[3]

'Direct observation' is to be understood in contrast with what Shapere calls 'indirect' or 'inferential' observation: observation in which the transmission of the information involves interactions that interfere with the bearers of the information and alter the information itself. For example, photons on the surface of the sun are ultimately generated from photons in the core, and in principle could be used to study the core region. But because of the many absorptions and emissions by which a packet of electromagnetic energy is transmitted from the core to the surface, the photons that emerge from the sun's surface have a different frequency than the ones in the core. So an inference has to be made from that surface information to conditions at the center of the sun. No such inference is required when we observe solar neutrinos. The latter only interact with other matter via the weak force, and consequently there is a very low probability of their being interfered with as they travel from the sun's core to detecting apparatuses on Earth. As a result, the information they carry is unaltered by interactions during the transmission, and can be taken to directly reflect conditions in the core.[4]

The four key components of the above conditions for direct observability are the source, the receptor, information, and the transmission of information. Shapere argues that scientists' use

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[3] Shapere (1982), p. 492.

[4] Shapere (1982), pp. 491-492.

of ‘direct observation’ in cases like the solar neutrino experiment presupposes a generalized notion of what it is to be a receptor or detector: a receptor is an instrument capable of detecting the presence of a (physical) interaction. From this perspective, the human eye is nothing but a receptor able to detect a certain range of electromagnetic interactions. Likewise, the detection apparatus in the neutrino experiment is a receptor able to detect weak interactions. Shapere’s point is that as science advances, the eye comes to be regarded as just a particular sort of electromagnetic receptor, there being other sorts of receptors capable of detecting other ranges of the electromagnetic spectrum, and as well as other kinds of interactions altogether. (I note in passing that this not only makes sense of ‘direct observation,’ but also of anthropomorphic metaphors scientists sometimes use to describe their instruments, as for example a scientist who describes the detector of a modern analytical instrument as the “eyes, ears and nose” of the machine.[5] Such talk suggests that, for scientific purposes, the functions of the senses can be carried out by non-human receptors just as well, and usually better, than human ones).

Two scientific features of Shapere’s criteria are worth noting. First, since current physics recognizes four fundamental types of interaction, four basic types of receptor are possible, corresponding to each interaction. Shapere adds that there are also four corresponding types of information “emitted” by objects, though he does not explicate either what he means by “information” or what it is for it to be “emitted” by an object. Second, the notion of observation supported by his conditions is heavily theory-laden, a feature Shapere seeks to defend against skeptical conclusions drawn from the thesis of the theory-ladenness of observation.[6] In fact, Shapere argues that satisfaction of the criteria requires background knowledge that can be divided into three theoretical components: the theory of the source, the theory of the transmission, and the theory of the receptor. The theory of the source consists of our knowledge

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[5] Lewin (1958), p. 20A.

[6] Shapere (1982), p. 514ff.

of the source and of why it "emits" a certain kind of information. The theory of the transmission consists of our knowledge of the processes by which the information is transmitted from source to receptor, including knowledge of what factors might interfere with the transmission. The theory of the receptor details the workings of the receptor apparatus and how it detects the interaction by which information is received. Together, these three theories provide justification for the claim that some source *x* has been directly observed according to (1) and (2).

Shapere's philosophical approach may be viewed as an attempt to "naturalize" scientific observation.[7] Though he does not elaborate on his version of naturalism, it is clear that human sense-perception has no special status in such "naturalized" observation. Indeed, humans have no necessary role in observation itself; they merely have to set up the receptor and use the information received and recorded by it.[8] True, the information must be transformed into a form accessible to, and hence perceivable by, humans, but a human perceiver need not be present when the information is received, recorded, or even processed into humanly-accessible form. In fact, human agency is completely purged from Shapere's two conditions on direct observation. Shapere notes the absence and an attendant objection to it, that the conditions fail to distinguish an observation-interaction from all other interactions that might be used for informational purposes but that have not been set up with the explicit intention of obtaining information, and which, presumably, would therefore not count as genuine observations. For example, a crater left by a missile may be studied to obtain information about the missile, but the crater would not thereby count as an observation of the missile. He entertains the suggestion that human intentions be incorporated as a third condition on direct observation, but rejects it on the grounds that "*it is precisely the assimilation of observation to the general category of 'interactions,' and*

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[7] Shapere (1982), p. 522.
[8] Shapere (1982), p. 509.

not its use by us, that constitutes the important point in understanding the role of observation in the search for knowledge and the testing of beliefs."[9]

Though I am sympathetic with Shapere's attempt to divorce the scientific concept of observation from sense-perception, in what follows I will argue that there is a reason, grounded in basic scientific practice, for resisting "the assimilation of observation to the general category of 'interactions.'" For the moment, I will point out a certain oddity in his analysis of observation. As noted above, he provides no account of what it is to be "information." In particular, he writes as if information were simply borne or "emitted" by objects, as if it were something like a natural property whose production requires no human labor. True, he acknowledges that human intervention is required to set up the receptor, but he holds at the same time that the information is already "out there," in transmission, and the receptor is merely a passive recipient of that information. The latter may need to be processed to be viewable by a human, but such processing occurs *after* the information has been received. The question I will address in the following section is whether such a purely passive reception of information is possible in measurement-based science.

3. Can there be a purely passive reception of information in measurement-based science?

Observation in most sciences crucially involves measurement, a term Shapere uses only occasionally and in passing. Measurement involves the collection of data points. The data points contain the information of interest to the scientist. The question of whether there can be purely passive reception of information, then, amounts to the question of whether there can be "raw" data, that is, data that has not been processed or manipulated by scientists. Todd Harris raises the question of whether there can be such a thing as "raw data" in the course of his 2002 analysis of data models, or representations of data.[10] He notes that in many cases what might be considered

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[9] Shapere (1982), p. 510. Italics in the original.

[10] Harris (2002), pp. 1511-1512.

to be raw data are in fact processed. Even in simple cases, like the reading of a thermometer, a certain amount of interpretation is involved: for example, it may be difficult to line up the mercury column of the thermometer with the temperature scale printed on the thermometer because of the meniscus at the top of the column and the refractive effects of the glass containing the mercury. The processing is even more evident with sophisticated instrumentation like an electron microscope. The production of an electron micrograph is an elaborate process that requires the specimen to undergo a lengthy preparation procedure that scientists manipulate in order to achieve the desired effect in the micrograph. They might also change the settings on the microscope to obtain this effect. The data produced by means of this instrument certainly seem to be the result of a significant amount of processing.

Harris considers other reasons besides manipulation or processing for thinking data might be raw. It might be thought to be raw because it is not influenced by theory. But, he points out, scientists frequently make decisions that affect the output of their instruments based on theoretical assumptions about the target system. Another reason for considering data to be raw might be that there is a hierarchy of representations of the target system. Lynch (1988) describes the practice of visual representation in the life sciences. Starting from an original, for example a photograph of the specimen, “a sequence of reproductions progressively modifies the object’s visibility in the direction of generic pedagogy and abstract theorizing.”[11] Harris points out that the original representation might be called “raw data,” since it is the starting point of the sequence, but it is not “raw” in the sense of being free of human manipulation or processing.

In addition to Harris’s objections to these uses of the concept of raw data, I will provide an argument against the very possibility of a purely passive reception of information in measurement. Here, I will draw on Davis Baird’s idea (assuming it originates with him) that measurement presupposes representation. He writes that

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[11] Lynch (1988), p. 229.

> [m]easurement presupposes representation, for measuring something locates it in an ordered space of possible measurement outcomes. A representation—or model—of this ordered space has to be built into a measuring instrument.[12]

Measuring instruments ranging from simple rulers to complex spectrometers employ such representations. The ruler or thermometer comes with a scale printed on it, and the ADC converter inside a spectrometer employs a bit-level scale to represent the electrical signal generated from the specimen. Besides measuring, scientific measuring instruments must also produce a phenomenon, like the signal, which is what is represented on the ordered space of possible measurement outcomes built into the machine.

Baird objects to the common expression, also used by Shapere, that measuring instruments "extract information" from a specimen.[13] He thinks it more philosophically prudent to say that "an instrument interacting with a specimen generates a signal, which, suitably transformed, can then be understood as information about the specimen." Baird provides two reasons for his view. First, regardless of how its output is to be interpreted, the instrument must be capable of producing a stable, public phenomenon in a regular and reliable fashion. For example, a spectrometer must be able to generate a signal independently of whatever information the scientist thinks might be obtainable from it. Second, by virtue of its semantic nature, information "carries meaning and hence eliminates possibilities." The signal must therefore be placed in a field of possibilities in order to be understood as information. Only once the production of a phenomenon is integrated with a material representation of a field of possibilities can a measurement be made.[14]

I claim that necessarily, this material representation (e.g., the scale) can only be a partial representation of the field. In general, the possible values of the quantity being measured will outstrip the representational capacity of the device. The true values must be approximated by

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[12] Baird (2004), p. 12.
[13] Shapere (1982), pp. 514-515.
[14] Baird (2004), p. 68.

picking material counterparts in the representation. The representing values therefore do not correspond exactly to the values they represent. The data exist only by means of this alteration, which allows the value of the measured quantity to be represented. I will illustrate my meaning with two examples.

First, the approximation inherent in material representation underlies the practice of recording only the significant figures of a measurement. The number associated with a measurement is obtained using some measuring device. The measurement always has some degree of uncertainty, which arises from the fact that the scale is not infinitely precise. Consider the following textbook example of measuring the volume of a liquid using a buret (Figure 1):

> Notice that the meniscus of the liquid occurs at about 22.15 milliliters. This means that about 22.15 mL of liquid has been delivered from the buret (if the initial position of the liquid meniscus was 0.00 mL). Note that we must estimate the last number of the volume reading by interpolating between the 0.1-mL marks. Since the last number is estimated, its value may be different if another person makes the same measurement … the first three numbers (22.1) remain the same regardless of who makes the measurement; these are called **certain** digits. However, the digit to the right of the 1 must be estimated and therefore varies; it is called an **uncertain** digit … In our example it would not make any sense to try to record the volume to thousandths of a millileter because the value for hundredths of a millileter must be estimated when using the buret.[15]

The material representation of volume as a set of marks on the wall of the buret forces the reader of the buret to estimate the value at the hundredths place. As Duhem pointed out long ago, in such measurements we cannot assert what the true value is for the parameter being measured; we can only assert, say, that the true volume is approximately 22.1 mL, and that the difference between 22.1 mL and the true volume does not exceed a few hundredths of a milliliter.[16] Furthermore, the measurement is completely silent as to the outcome beyond the last significant figure.

This approximation stemming from the limits of material representation also affects the sophisticated experiments Shapere has in mind. In NMR spectroscopy, for example, a specimen containing magnetic nuclei is placed in an applied magnetic field. Irradiation of the specimen

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[15] Zumdahl (1993), p. 10.

[16] Duhem (1982 [1914]), p. 134. He uses the example of a thermometer rather than a buret.

causes the nuclei to precess about the direction of the field. The precession produces a voltage in the instrument. An analogue-to-digital converter (ADC) is used to convert the NMR signal from a voltage to a binary number which can be stored in computer memory (Figure 1). The ADC samples the signal at regular intervals, producing a representation of the signal as data points. The output of the ADC is a number, and the range of different numbers that the ADC can output is determined by the number of binary bits used by it. The total number of possibilities is 2 raised to the power of the number of bits. So for example, a three-bit ADC can produce output having only eight values: 000, 001, 010, 011, 100, 101, 110 and 111.

Though the output of the three-bit ADC is restricted to one of eight levels, the waveform that it is digitizing varies continuously. As a result, the instrument is forced to simply pick which of these levels is closest to the input. The output of the ADC is therefore an approximation to the true waveform. The degree of approximation of the digital representation can be reduced by increasing the number of bits, which makes more levels available, but of course it cannot be eliminated altogether. Furthermore, technical considerations apparently cap the increase of bits at 32.[17]

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[17] For a discussion of the digitization process in NMR, see Keeler (2010), section 13.5.

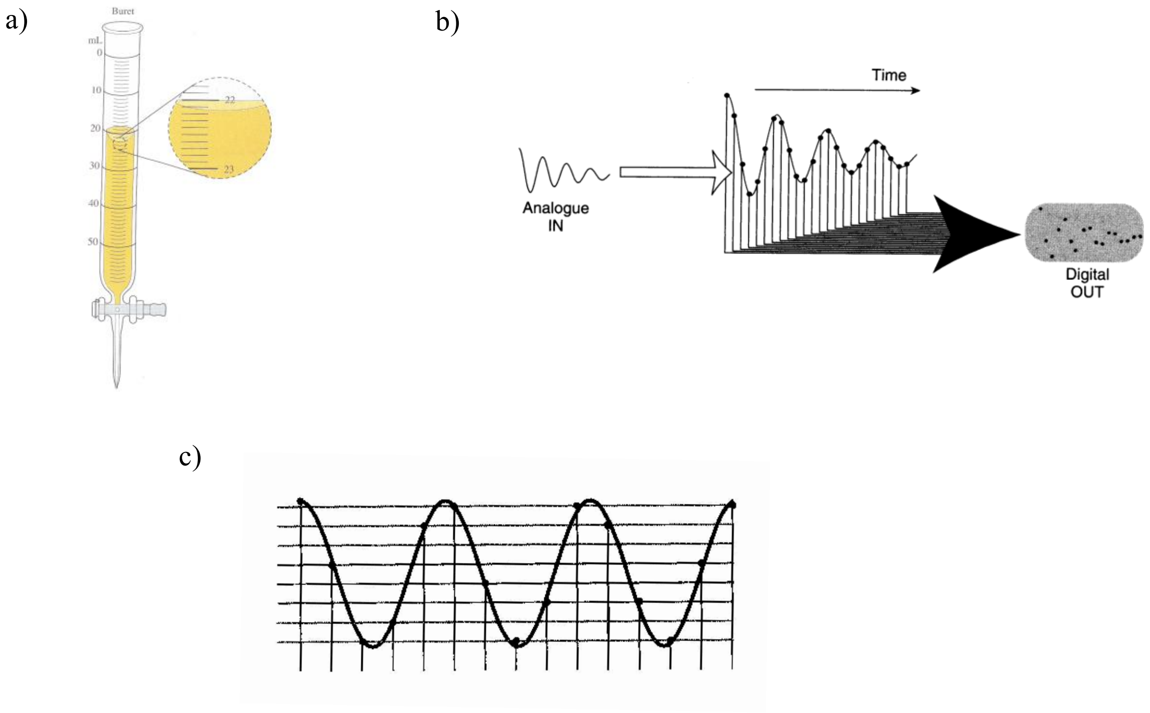

Figure 1. a) Diagram of a buret. Source: Zumdahl (1993), p. 10. b) The digitization of an analog NMR signal. Source: Levitt (2008), p. 75. c) The eight levels of a three-bit ADC. Source: Keeler (2010), p. 489.

As these examples illustrate, it follows from the very nature of the material representation of the possible measurement outcomes that the data thus collected will deviate from the true values in a manner reflecting the limited number of possibilities that can be thus represented. The signal has to be, so to speak, “filtered” through the representation in order to yield data. Since the representation reflects a human purpose, it follows that all data are the product of purposeful manipulation. Data are always already processed.

I have stressed the fact that measurement devices employ a *material* representation, because ideal representations do not have the same limitation. Recognizing the field of possibilities that we might want to represent materially requires thought, typically in terms of a theoretical understanding of the possible outcomes. Any rational number may be represented in thought, for example by calculating it using the appropriate formula. Such theoretical facts, as Duhem called them, are completely precise, which allows us to represent measurement outcomes precisely *in theory* that can only be represented approximately in our instruments: “To say that the temperature of a body is 10 °, or 9.99 ° or 10.01 ° is to formulate three incompatible facts, but these three incompatible facts correspond to one and the same practical fact when our thermometer is accurate only to a fifth of a degree."[18] In principle, then, any actual quantity in the world can be represented theoretically without approximation (as long as it can be expressed as a rational number). But the constraints of material representation entail a reduction in representational power, as the fine-grained facts of theory are reduced to the more coarse-grained facts of practice.

4. Putting the human back into observation

In short, I have been arguing that measurement necessarily requires an active transformation of the signal received from the specimen. This transformation is what turns the signal into a source of information. Let us now see how these considerations affect the concept of scientific observation.

Recall Shapere's analysis:

x is directly observed (observable) if:

1. information is received (can be received) by an appropriate receptor; and
2. that information is (can be) transmitted directly, i.e., without interference, to the receptor from the entity *x* (which is the source of the information).

My suggestion is that, if the arguments in the preceding section are accepted, then two things need to be added or modified in his analysis: that which is received, and how the reception results in a measurement. I propose the following revised analysis:

x is directly observed (observable) if:

1'. the signal from *x* is received (can be received) by an appropriate receptor;

and

2'. the signal is (can be) transmitted directly, i.e., without interference, to the receptor from the entity *x* (which is the source of the signal).

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[18] Duhem (1982), p. 139.

3'. the signal is represented on a space of possible values.

My claim is that the revised analysis describes more accurately how actual measurements are produced. The two changes are, of course, that ‘information’ has been replaced by ‘signal’ and that a third condition 3’ has been added that reflects the nature of representation in measurement, as discussed above. The point is that information is not automatically obtained in virtue of receiving a signal; it has to be produced by means of a representation.

It may be complained that my analysis does not capture the sense of an unmediated observation of the source that is perhaps implicit in the physicists’ talk of “directly observing” the sun’s core, because it imputes more processing to such observing than Shapere’s does. But it seems to me that the main point of invoking the notion of “directness” is to refer to observational situations in which there is no interference in the transmission. And this feature has been retained, in 2’.

My analysis makes manipulation essential to the acquisition of information. It follows that it is simply not true that observation, to the extent that it involves measurement, can be assimilated to the general category of “interactions,” as Shapere would have it. The “interaction” between instrument and specimen must be represented in a humanly conceived and produced space of possibilities in order for evidence to be acquired, and therefore in order for the epistemic function of “observation” to be fulfilled. There is no observation without representation.

But then, these changes throw Shapere’s project of naturalizing scientific observation into doubt. The representation requirement entails that human intervention is a necessary condition for such observation. Though Shapere is correct, I think, to distinguish between the evidential role of observation and the fulfillment of that role by sense-perception, he is wrong to think that doing so thereby relegates human agency to the mere use of information. On the contrary, human agency is involved in the very production of the latter by way of the representational operations carried out by the instrument.

It may be objected that the "representational operations" of the instrument are purely mechanical, and therefore do not involve human agency. The objection assumes that a human has to be present in order to intervene on something. This is clearly false, as shown by automated production processes, mouse-traps, and innumerable other examples where it would be absurd to deny that humans are intervening, but in which the actual presence of a human is unnecessary.

5. Observation and empiricism

It is well to recall why the naturalization of scientific knowledge is important for Shapere. He holds that the old empiricist view of knowledge was on the right track. Knowledge is in the end founded upon experience, where the latter is supposed to yield observational support for beliefs. He notes that what count as observations depends upon our theories of the world and of particular effects, so that there is no such thing as a purely observational sentence. But, he argues, the fact that observing depends on theories does not have the anti-rational consequences that have sometimes been drawn from the thesis that all observation is theory-laden.[19] Indeed, Shapere holds that the assimilation of observation to 'interactions' "reflects the fact that 'observation' has been, or at least has moved far toward being, integrated with the larger body of our best-warranted beliefs about nature."[20] Thus, the theory-ladenness of observation does not make it "highly shaky or arbitrary," but rather allows science to bring to bear "the best information it has available" in order to learn new things about the world.[21]

Though it is not very clear, I take the claim about the integration of 'observation' with our best-warranted beliefs about nature to mean the following, at least as far as its practical implications are concerned: an observation is just an interaction between a signal and a receptor,

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[19] Shapere (1982), p. 514.
[20] Shapere (1982), p. 510.
[21] Shapere (1982), p. 514.

or, in his vocabulary, just the reception of information released by a source and received by the receptor. The interaction must satisfy conditions (1) and (2) in order to count as an observation. Provided that the theories of the release of information by the source, of the transmission of the information, and of the receptor of the information are justified, then when the observation is made we are justified in believing that the source *x* has been observed. This belief can now be added to the larger body of our best-warranted beliefs about nature, and serve as a foundation for further additions to our knowledge, in particular the inferences that can be made about the source on the basis of the observation. The solar neutrino experiment allows us to directly observe the sun's core, and we derive various properties of the core from that observation.

On my alternative analysis of 'observation,' however, an observation is essentially a representation of a signal. It follows that the claim that all knowledge is based on observation is equivalent to the claim that all knowledge is based on representation (at least as far as the knowledge produced by measurement-based sciences is concerned). But, I have been arguing, the representation under discussion here essentially contains a non-experiential component, for the material representation of possible measurement outcomes is a precondition for having any "experience" of the signal at all. Therefore, the traditional empiricist view that all knowledge is based on experience does not hold for such science, at least if by 'experience' is meant some sort of raw, unstructured (by us) informational input from nature. It would be more accurate to say that all knowledge is based on representations of inputs from nature, of which more later.

Now, it may be asked where the representations come from. Can they not be derived from experience? The answer is yes. For example, the two fixed points and unit interval between them that form our temperature scale were initially specified in terms of the expansion of mercury. This specification may appear to be merely conventional. Eventually, however, Thomson and Joule were able to characterize the scale in terms of absolute temperature, which could be reduced to measurable quantities.[22] So perhaps one could argue that the scale was eventually derived from experience. But such derivations merely push the question back. The empirical establishment of a scale will itself require other scales, whose establishment in turn requires scales, and so on. So long as we are doing measurements, a representation of the possible measurement outcomes is a precondition for experience.

I conclude that Shapere is faced with a dilemma. If he retains the traditional philosophical concept of observation that involves sense-perception, then the resulting philosophy of science will have to treat scientists' talk of "directly observing" things like the core of the sun as loose, metaphorical, sloppy or whatever. On the other hand, if he uses a concept of observation based on scientific practice, then he will have to give up his defense of empiricism. Therefore he cannot consistently meet both aims of his paper: Defend a concept of observation based on scientific practice while at the same time defending empiricism.

6. Conclusion: saving the foundation

In conclusion, I would like to suggest a solution to the dilemma. Shapere uses the expressions "all knowledge rests on observation" or "rests on experience" to characterize "traditional empiricism."[23] We need to distinguish two aspects of this characterization. First, there is the empiricist aspect, according to which experience forms the foundation for justifying scientific claims to knowledge. This is the sense in which all knowledge rests on *experience*. But there is also a foundationalist aspect, according to which scientific knowledge relies on a foundation for its justification (in contrast, say, to a coherentist view of knowledge). This is the sense in which all knowledge *rests on* experience. My suggestion is that by disentangling these two aspects, we might find a way of saving what Shapere admires in empiricism, while retaining a concept of observation that does not depend on sense-perception.

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[22] Chang (2004), ch. 4.

[23] Shapere (1982), pp. 485, 508, 522.

Though I hope to have provided grounds for thinking that Shapere has to give up the empiricist aspect, I think it is possible to save his foundationalist intuition. That intuition, I take it, is that our knowledge of nature is founded on inputs from the natural world. Why cannot those inputs be representations? Consider an example from art. We are presented with a painting of a subject *x*. The painting is alleged to represent the subject with a certain degree of accuracy and detail. Can we have knowledge of the subject if our only access to it is the painting? There are probably several answers that can be given here, depending on one's preferred epistemological stance, but a tentative response, analogous to Shapere's defense of scientists' usage of 'direct observation,' is to ask whether our best information about the conditions of production of the painting warrants taking it as a representation of the subject to the alleged degree of accuracy and detail. Is the subject such that it could possibly be represented in this way? On a naïve view of representation, anyway, an accurate painting of a person will not look like a bridge, for example.[24] Does the subject exist? Were the conditions of viewing adequate? Even if we do not have first-hand access to the subject, our background knowledge of it can help us assess representational accuracy and detail. If the painter was trying to paint a mountain, but clouds partially blocked his line of sight, then there might be reason to question the accuracy and detail claimed for the painting. Our background knowledge may even tell us that the mountain does not exist, in which case we cannot claim to know a mountain in the world by way of the painting. Is the painter a reliable producer of paintings? If his vision is poor, or he is a bad painter, then these might be further reasons to doubt the fidelity of the painting.

On the other hand, if there are no good reasons for doubting that the conditions of production warrant confidence in the representational accuracy and detail of the painting, then at

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[24] For the purposes of this paper I am setting aside the difficult questions of what exactly a (scientific) representation is, and what are the conditions for an accurate representation. I do not think my argument depends on the precise answers to these questions, so long as they can be answered.

least prima facie there seem to be good grounds for taking the representation as a basis for our knowledge of the subject.

Of course, in our case the subject is a scientific phenomenon, typically a signal, but we can ask similar questions of it as in the painting example. Are our causal models of how the specimen will respond to a given stimulus reliable? Were the experimental conditions for the generation of a reliable signal satisfied? Is the detection apparatus such as to produce a representation of the signal to the desired degree of accuracy and detail?

A realistic painting of a subject cannot be, I think, simply true or false of the subject in the way that a proposition can be. But it can be more or less accurate and more or less detailed. It can be false in the sense of bearing identifiable discrepancies with the subject, and true in the sense of their absence. Likewise, the data can be a more or less accurate and precise representation of the signal.

It may be objected that a representation is not an input from the natural world, since it is man-made. Therefore I cannot save Shapere's foundationalist intuition by appealing to representation. The objection assumes that if something is man-made, then it cannot be an input from the natural world. I will demonstrate the falsity of this assumption by drawing on an analogy with economic production. The outputs of production processes are frequently inputs for other production processes. For example, a mine produces an output when it extracts ore from a vein. This ore then serves as an input in the washing process (which removes contaminants from the ore). The extracted ore to be washed is clearly a natural material, but it has been "filtered" through or given form by the extraction process. The material nature of ore ensures that there is continuity through the transformations wrought on the material as it passes through the various phases of production. The extracted ore entering into the washing process is thus both produced by humans yet also an input from the natural world. Therefore, the assumption is false.

In the case of the ore, nature furnishes a material substratum that persists through the changes of form wrought by humans. The situation is reversed in the case of the signal. There is continuity of form through changes of material substratum. For example, the NMR signal is called a “free induction decay” because it decays in a characteristic manner. The decay is due to the impossibility of maintaining exact synchrony between the precessing magnetic nuclei. The digitized representation produced by the ADC decays in the same way, with approximately the same amplitude and wavelength. There is thus continuity of form, even though the waveform is now materialized in the computer hardware rather than in an electric current. By analogy with the ore, then, the representation of the signal is both produced by humans yet also contains input from the natural world. My suggestion is therefore compatible with the foundationalism at issue here.

To summarize: Dudley Shapere provided a valuable study of what observation amounts to in contemporary physical science. The study is valuable because it provides good reasons for reconsidering the role of humans in this fundamental component of scientific method. I think Shapere is on the right track in minimizing the role of sense-perception in his account of scientific observation. On the other hand, he errs in excluding human agency from playing any active role in observation. I have argued that human agency enters into observation by way of the representational function of measurement. I have argued that though this aspect of observation conflicts with traditional empiricism, it is compatible with a view of scientific knowledge as being based on empirical inputs, even though these may involve more than just “experience.”

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