Perspectival Instruments

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Abstract

Despite its potential implications for the objectivity of scientific knowledge, the claim that 'scientific instruments are perspectival' has received little critical attention. Yet understanding 'who's point of view?' instruments might depend upon is invaluable to understanding how scientific knowledge is obtained. This paper shows that whilst the unqualified claim that 'scientific instruments are perspectival' is epistemically unproductive, once finer-grained notions of perspectives are taken into account, perspectivism can be used to develop new strategies for resolving well known epistemic problems in relation to scientific instruments, such as conceptual relativism and theory-ladeness.

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Contents

1 Introduction

A scientific instrument is any apparatus, simple or complex, used to investigate the natural world through observation and experimentation.[1] For example, microscopes, cloud chambers, and spectrographs are all scientific instruments through which we can investigate the world. According to the traditional view, the results of investigations undertaken with scientific instruments are not only invaluable for understanding the world around us, but such results are also objective – call this the objective view of scientific instruments.

Opposed to the objective view are two related theses. The first thesis is the theory-ladeness thesis, according to which the background theories, beliefs, or presuppositions of an observer, that is their perspective, may affect their observations (Hanson 1958). The

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[1] For historical accounts of instruments, see Turner (2013), McConnell (2013), Brenni (2013) and Hackman (1989). For a conceptual classification, see Lauwerys (1937).

second is the conceptual relativism thesis, according to which there is no ready world that all perspectives can latch onto, instead different perspectives construct the world differently (Kuhn 1962). Both theses represent problematic epistemic challenges in relation to the objective view of scientific instruments. Whilst both problems have been extensively discussed in the literature in relation to observation and experimentation, comparatively few discussions have focussed specifically on scientific instruments (Chalmers 2003, Heidelberger 2003, Baird 2004).[2]

In recent years, perspectival realism has emerged as a new view in philosophy of science, opposed to the objective view. Perspectival realism is a view equally committed to the mind-independence of the world and to the situatedness or perspectivity of scientific knowledge (cf. Massimi 2018c, Giere 2006).[3] According to this view, particularly as defended by Giere (1999; 2000; 2006), and recently by Evans (2020), scientific instruments should be thought of as being perspectival and as delivering 'perspectival knowledge'. Prima facie, this means that scientific instruments can only yield knowledge from a 'point of view'. Who's point of view? Giere's view, as we shall see, is too coarse grained for answering this question. It will thus be shown that the interesting content of the claim that 'instruments are perspectival' reduces to the two old, much discussed, epistemic problems of conceptual relativism and theory-ladeness.[4]

The novel content of this paper consists in showing that once finer-grained notions of perspectives are taken into account – that is, 'broad perspectives' and 'narrow perspectives' – perspectivism can be used to develop *new strategies* for resolving the two well known epistemic problems.[5]

The first strategy is developed to respond to conceptual relativism brought about by 'instrumental incommensurability', understood as a form of discontinuity or incommen-

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[2] See Laudan (1990) for a comprehensive discussion of both problems, and New Experimentalists, such as Hacking (1983), Franklin (1990; 1986; 2015), Mayo (1996), Franklin and Perovic (2019) on epistemic strategies to overcome the theory-ladeness of experiments, and other sceptical challenges.

[3] See Creţu 2020c for an accessible overview.

[4] For more general problems with perspectivism, beyond those related to scientific instruments, see Chakravartty (2010; 2017), Chirimuuta (2016), and Morrison (2011). For a sustained defence of perspectivism see Massimi (2012; 2018a;b;c;d).

[5] Broad perspectives are discussed by Massimi (2018c) and narrow perspectives are discussed, in different ways, by Massimi (2012) and Creţu (2020a). The current paper builds on and extends these earlier analyses in a systematic way and applied in a new context.

surability at the level of the instruments themselves. The strategy is developed around broad perspectives, which are understood as culturally and scientifically situated theoretical frameworks typical of a scientific community (Massimi 2018c). It is shown that far from constituting a novel epistemic challenge, the dependence of instruments on broad perspectives, when closely analysed, provides instead the means to mount a novel response to the old epistemic challenge of conceptual relativism.

By recourse to the history and philosophy of science three points are established. First, it is established that objectivity standards (cf. Daston and Galison 2007) – which govern the use of scientific instruments – are not tied to any particular broad perspective (and thus if they are perspectival they are so in a much broader sense). Second, it is established that when broad perspectives change, objectivity standards do not change concomitantly. And third, by drawing on two brief case studies – the history of the cloud chamber (Galison 1997) and of stellar classifications (Hoffleit 1991) – it is established that scientific instruments and their outputs can cut across both broad perspectives and changing objectivity standards. Thus, as long as shifts in objectivity standards are not abrupt and discontinuous and do not correspond to shifts in broad perspectives, knowledge derived from scientific instruments can be objective despite changes in broad perspectives.

The second strategy is developed around narrow perspectives to respond to the theory-ladeness challenge in relation to scientific instruments. It is shown that narrow perspectives, which constitute the working stances of scientists, are restricted neither to one theory nor just to theory. As such, narrow perspectives contain within them cross-perspectival justificatory tools to render instruments and their data valid and objective.

This paper will be of value to philosophers, scientists, and historians who take scientific instruments to deliver knowledge about the world. Since the challenges posed by perspectivalist claims threaten to undermine the process of scientific knowledge production, any disruption to the the process of using instruments to obtain scientific knowledge is worth investigating in its own right. Furthermore, the paper presents a general strategy for turning an unproductive perspectival claim, e.g., ‘instruments are perspectival’, into novel solutions to well known problems, highlighting the epistemic productivity of fine-graining perspectival claims.

The paper is structured as follows: Section 2 examines intuitive notions of 'perspective' and clarifies the account proposed by Giere (1999; 2000; 2006). In Section 3 the problem of conceptual relativism is analysed in terms of instrumental incommensurability between broad perspectives. Thus reframed, the problem can be resolved via reference to two novel responses, the first 'objectivity led', the second, 'instrument led'. In Section 4 the problem of 'instrumental theory-ladeness' is separately resolved with reference to individual scientists' narrow perspectives. It is ultimately demonstrated that scientific instruments can be understood as perspectival in two distinct senses, each leading to distinct challenges for which systematic responses are provided.

2 Perspectives Clarified

To determine what, if any, the import of scientific perspectivism is in relation to scientific instruments, and whether in this context it brings about either new epistemic challenges or new solutions to existing epistemic challenges, two steps are necessary. First, it is necessary to understand what kind of 'perspectives' are relevant to instruments. Second, it is necessary to understand in what ways scientific instruments depend on relevant perspectives and what epistemic consequences may result from such dependence. Only once these steps are undertaken, can an evaluation of the claim that 'scientific instruments are perspectival' be undertaken.

2.1 Intuitive Perspectives

Consider, to begin with, two of the most common meanings associated with perspectives: the first, a private, personal point of view, the second, the human point of view. On the one hand, to say that instruments are perspectival because they yield knowledge from one's own point of view is philosophically trivial. We interact with the world from our point of view and not from another's point of view, and in a deep sense we cannot entirely escape our point of view, and thus to say that whatever we do know is from our own point of view, in not particularly epistemically productive. On the other hand, to say that instruments are perspectival because they yield knowledge from the human point of view is similarly unproductive. We cannot know from a non-human point of view, and thus, whatever we do know from the human point of view is all we can know. Thus, to claim that instruments are perspectival because they are dependent on the human perspective or the personal perspective is to claim something that is at the same time trivially true and epistemically unproductive.

One might nevertheless take the claim that instruments are dependent on the human perspective to mean something about the way humans 'see' with and through instruments Giere (1999; 2000; 2006). Not all human beings are equipped with the same visual system. Though most human beings have trichromat vision which enables them to see the full-spectrum of colours, some human beings are colour-blind. Most frequently, colour-blind humans cannot distinguish red and green and in some cases complete colour-blindness precludes the experience of colours. If instruments are perspectival because the results they yield depend on the visual system which manipulates them, the perspectivity of instruments might not be trivially true. In and of itself the claim that different visual systems can yield different kinds of knowledge about the world is not epistemically problematic. Suppose Cat and Pat are using exactly the same microscope to look at an insect wing. If Cat cannot see any colours and Pat can see colours, they will naturally see the insect wing differently, Cat from a monochromatic perspective, Pat from a colourful perspective. Their perception of the insect wing will be inherently different, one without colour information, the other with colour information. Thus, due to their different visual systems, Cat's and Pat's investigations with the same instrument can yield different kinds of knowledge about the world. What this example suggests, however, is that the perspectivity under discussion has nothing to do with the instrument in question. Cat and Pat would see the insect wing differently with or without the instrument, since it is the visual system that constitutes the relevant perspective and not anything to do with the instrument itself.

2.2 Scientific Perspectives

We may further assume that what makes instruments perspectival are the following perspectival features: i) "they respond only to a limited range of aspects of their environment" (Giere 2006, p. 41), ii) "even for those aspects of the world to which they do respond, the response is limited" (id.), and iii) they "have some limitations on their ability to discriminate among inputs that are theoretically distinct" (p. 42). The first two features have been recently discussed by Evans (2020) in his account of 'perspectival objectivity' and thus points of agreement or disagreement with Evans shall be noted below.[6] Bearing this in mind, let us now consider each point in turn.

The claim that scientific instruments are perspectival because they have a limited range is hardly controversial. It is simply to say that a scientific instrument will deliver knowledge of only some aspects of the world but not others. This is nevertheless self-evident: every observation from the vantage point of a particular instrument is limited to the range of inputs detectable by the relevant instrument. For example, a telescope is useless for detecting positrons simply because the energy scale of the positrons is not detectable by telescopes. We, as humans, are similarly 'limited' in that "we are sensitive only to a certain set of variables, namely ones that can be detected by sight, sound, touch, and taste" (p. 5) as Evans (2020) points out. And so, to take this as more than a trivial observation regarding our sensorial range, at best belabours a point about our human capacities and limitations. Thus, returning to scientific instruments, unless they are supposed to provide more than partial access to nature, it is not clear that the 'perspectival' addendum does any philosophically fruitful work as applied to scientific instruments.[7,8]

The second respect in which instruments can be deemed perspectival is that they have a limited response to limited inputs. To use Giere's example, "[a] camera responds only to radiation to which its film or more recently, its digital sensors are attuned" (p. 42).

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[6] Evans' claim is that whilst certain facts are perspective-dependent (though not observer-dependent), such facts can nevertheless be objective since within a perspective, for a given feature of the world, "there is an (intersubjectively) objective fact of the matter concerning that feature" (Evans 2020, p. 6).

[7] Giere himself acknowledges that "[t]here is no universal instrument that could record every aspect of any natural object or processes" (Giere 2000, p. 11).

[8] This lack of scope is also pointed out by Massimi (2012), pp. 29-30.

Since "[e]very instrument interacts with the world only from its own particular perspective" (Giere 2000, p. 10), and "part of the perspective of any instrument is determined by its built in margin of error" (p. 11), instruments can only yield partial, perspectival knowledge. This, then, as Evans (2020) emphasises, "is a trivial observation, in the sense that we cannot model undetectable properties or behaviour of a system in terms of undetectable variables" (p. 5). According to Evans, this observation discloses, nevertheless, something about the limitations of the perspective through which we can interact with and model the world. Whilst Evans is right to emphasise that this point exposes the role of our "idiosyncratic capabilities to interact with, and model, reality" (id.), the claim that instruments are perspectival in this regard, accomplishes little beyond circumscribing the perspective of the instrument, from, evidently, our own vantage point.

The third respect in which instruments are judged to be perspectival consists in their inability to discriminate between theoretically distinct inputs. Prima facie this may strike one as a misplaced charge since instruments do not have agency and so they are not meant to distinguish between theoretically distinct inputs. But, since Giere insists that "claims about what is observed cannot be *detached* from the means of observation" (Giere 2000, p. 48) and that "[o]ne cannot detach the description of the image from the perspective from which it was produced" (p. 56), the indiscriminateness of instruments is due to their theory-ladeness. Realists, relativists, positivists, and pragmatists alike have long agreed that "theories are involved in the construction and interpretation of instruments" (Laudan 1990, p. 47) and that "theoretical assumptions go into determining the boundary conditions supposed to apply to any situation under scrutiny" (id.). One may nevertheless insist that there is something deeply perspectival about cases of circular theory-ladeness, that is cases in which the theory of the instrument and the theory of the phenomena are mutually reinforcing. Whilst this is a legitimate worry (dealt with in section 4), it is not a particularly novel worry. Thus, once again, perspectivism, à la Giere, does not seem to possess novel and productive epistemic implications beyond what comes from rebranding theory-ladeness as perspectivism.

A more promising route is to understand the claim that instruments are perspectival as highlighting the dependence of instruments on different kinds of perspectives. We have seen how two different perspectives, the personal perspective and the human perspective can come to bear on instruments, though we have found the resulting perspectivity to be epistemically unproductive. Some of the options suggested by Giere, such as understanding a perspective as “a way of constructing scientific models” (Giere 1999, p. 79) or as a particular culture (Giere 2013) are too underspecified to be epistemically productive also. Yet, other notions, such as the standpoint of a scientific community, for example the Newtonian or Aristotelian perspective, or the observational standpoint of an observer or of an instrument (Giere 2006), whilst not sufficiently fine-grained in Giere’s account, constitute more promising routes for further investigation. In particular, two fine-grained notions of perspective – broad perspectives (Massimi 2018a) and narrow perspectives (Massimi 2012, Creţu 2020a) – can be exploited to deliver novel solutions to both conceptual relativism and theory-ladeness, as will be shown in the next two sections.

3 Broad Perspectives

This section explores the potential benefits of thinking of perspectives as historically and intellectually situated scientific frameworks typical of a scientific community, along the lines of Massimi (2018a). According to Massimi (2018a), such perspectives, let us call them broad perspectives, encompass “(i) the body of scientific knowledge claims advanced by the scientific community at the time; (ii) the experimental, theoretical, and technological resources available to the scientific community at the time to reliably make those scientific knowledge claims; and (iii) second-order (methodological-epistemic) claims that can justify the scientific knowledge claims so advanced” (p. 343). Thus defined, broad perspectives are better thought of not as a specific theory, but as research traditions.[9] Like research traditions, broad perspectives sponsor a variety of norms, background assumptions, ‘narrow perspectives’,[10] and theories alike, as well as theories about instruments,

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[9] This is a gloss on Massimi (2018a), who acknowledges, but does not clarify, the “important dissimilarities between the diachronic [historical practices] and the synchronic [contemporary modelling practices] notion of scientific perspectives” (p. 343.).

[10] More on ‘narrow perspectives’ in section 4.

their operation, and their interpretation.[11]

However, whilst each such perspective can produce through its instruments and their outputs its own conceptualisation of the world, any such conceptualisation can become essentially non-transferrable across broad perspectives, leading to a form of incommensurability – let us call it instrumental incommensurability – which can lead, in turn, to conceptual relativism. In what follows, two novel responses to instrumental incommensurability are offered, an 'objectivity led response' and an 'instrument led response'. But, before we turn to these two responses it will prove instructive to understand how the challenge arises.

3.1 Instrumental Incommensurability

Broad perspectives, understood as research traditions, articulate, through the elements they sponsor, particular conceptualisations of the world. For example, broad perspectives sponsor objectivity norms, and objectivity norms, in turn, govern the use of scientific instruments. If such objectivity norms are perspectival [since embedded within a particular broad perspective], this might suggest that instruments and their outputs might themselves be found to be perspectival. Were this to prevail, one might rightly conclude that instruments cannot yield objective knowledge because they are essentially laden to a particular point of view (albeit a broad one in this case). And thus, broad perspectives, like their Kuhnian predecessors, could lead to pervasive Kuhnian "paradigm-ladeness" and further problems thereto.

One particularly thorny problem is conceptual relativism, typically brought about by some form of incommensurability. Conceptual relativism is an old problem for scientific knowledge (see Laudan 1990, and more recently Baghramian and Carter 2019), traditionally not directly concerned with scientific instruments. Let us nevertheless assume that conceptual relativism can be brought about by some form of discontinuity or incommensurability at the level of the instruments themselves, let us call this 'instrumental incommensurability'. More precisely, let us assume that conceptual relativism can

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[11] See Laudan (1977) on research traditions and theories, and Creţu (2020a;b) for the relation between research traditions, (narrow) perspectives, and theories.

occur if and when broad perspectives change and such change leads to either knowledge of instrument building and operation or knowledge delivered by instruments becoming essentially non-transferable from one broad perspective to the next. The non-transferability of knowledge of instrument building or knowledge delivered by instruments can occur in at least three ways:

a) when there is physical non-transferability of instruments and their outputs across broad perspectives;

b) when non-transferability of technical knowledge occurs, understood as either practical or as theoretical knowledge of instrument-building and operation, or finally,

c) when conceptual non-transferability of instruments and their outputs occurs.

Let us briefly examine each in turn. Broad perspectives are extended in time and thus a) the physical non-transferability of instruments, as well as of their physical outputs is unfortunately unavoidable. Instruments may become irreproducible on certain timescales due to lack of material resources or they can become obsolete when more efficient alternatives are developed (i.e., less costly, more sustainable etc.). Instruments are also likely to deteriorate, can be moved, can fall into disrepair or fall pray to accidents and natural disasters. All these possibilities can make instruments, as well as their outputs, physically non-transferrable across broad perspectives. This kind of non-transferability, even if seen as some form of broad perspectivity, would nevertheless be entirely accidentally located within a broad perspective. For accidental occurrences that may lead to the destruction of instruments to coincide with the cut-off point of the transition from one broad perspective to another is not only an entirely contingent matter, it is also exceedingly unlikely. If this were nonetheless to occur, it could lead to a form of (radical) conceptual relativism brought about, inter alia, by instrumental incommensurability between broad perspectives. To be precise, since different instrumental perspectives can be said to construct the world differently, any discontinuity between such perspectives may preclude any commonly established facts between the relevant perspectives, leading thus to conceptual relativism. Whilst this is a serious problem for the progress of science, conceptual relativism is neither a distinctively perspectival challenge (but an old Kuhnian challenge), nor is it a challenge specific to, or restricted to, scientific instruments.[12]

Unlike the physical non-transferability of instruments, b) the technical non-transferability of instruments is more likely to occur.[13] Yet, like the physical non-transferability of instruments, technical non-transferability amounts to the same type of Kuhnian challenge, since non-transferability precludes the possibility of commonly established facts (because the facts can no longer be produced, recognised etc.). Thus, whilst one can rightly take the technical non-transferability of instruments as a form of perspectivism, it remains to be shown that this kind of perspectivism is distinctively different from Kuhnian paradigm-ladeness which can be said to lead to conceptual relativism via instrumental incommensurability.

Finally, c) the conceptual non-transferability of instruments and their outputs across broad perspectives constitutes an equally serious problem as their technical non-transferability. If instruments and their outputs are conceptually laden to broad perspectives, then each broad perspective produces through its instruments and their outputs, its own conceptualisation of the world. To put it differently, the non-transferability of instruments and their outputs across broad perspectives means that all knowledge yielded by instruments can only be knowledge from within a perspective. This amounts to a type of perspectivity akin to conceptual relativism. Insofar as perspectivity amounts to conceptual relativism, there is, once more, no novel epistemic import of perspectivity. However, whilst conceptual relativism is not a distinctively perspectival challenge, two distinctively perspectival responses are available in relation to instruments, as will be argued in the remainder of this section.

An important clarification is in order before we proceed to the two responses. It was thus far assumed that objectivity norms are perspectival, that is, that they are specific to

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[12] Conceptual relativism, typically associated with Kuhn, has given rise to a vast literature, not specifically tailored to scientific instruments, and as such, it shall not be dealt with here. Two different responses to conceptual relativism, tailored to the case of scientific instruments will be offered in sections 3.2&3.3. For a general and clear discussion of the intricacies of relativism and different solutions, see Laudan (1990).

[13] See Hicks (2017) for a fascinating case of technical discontinuity and Galison (1997) for technical continuity in particle physics.

a broad perspective.[14] It was further assumed that if broad perspectives are regarded as insular and disjointed, then changes in broad perspectives automatically lead to wholesale changes, including changes in objectivity standards, which can bring about conceptual relativism. Yet there are strong reasons to resist the assumption that objectivity standards are perspectival in the way previously assumed for three main reasons:

i. first, the scholarship on the history of objectivity suggests that objectivity standards are not tied to any particular broad perspective (and thus if they are perspectival they are so in a much broader sense);

ii. second, when broad perspectives change, objectivity standards do not change concomitantly; and,

iii. third, and most importantly, scientific instruments and their outputs typically cut across both broad perspectives and changing objectivity standards.

The first two reasons can be combined to mount a novel 'objectivity led' response to the instrumental incommensurability challenge to which we turn to in 3.2, whilst the third reason guides a novel 'instrument led' response to which we will turn to in 3.3.

3.2 Objectivity led Response

In this section it is shown that norms or standards of objectivity are not inherently tied to any particular broad perspective nor do they necessarily change concomitantly with any broad perspective. On the contrary, it is shown that older standards can survive alongside succeeding predominant standards, even past the predominance of the succeeding standard. For example, as Daston and Galison indicate, 'truth-to-nature' survived not only alongside 'mechanical objectivity', but also alongside 'structural objectivity', and trained judgement' (all of which are detailed below). Thus, if, as Daston and Galison (2007) suggest, objectivity standards changed first and foremost in response to particular subjectivity threats, such as idealisation, distortion, or automation, we can reasonably assume that each standard of objectivity 'strove' away from perspectivity to apersepctivity.

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[14] Note that a similar assumption would be warranted within Giere's (2006) scientific perspectivism.

Hence, even if objectivity standards are perceived as in some way perspectival, continuity in objectivity standards over and above changes in broad perspectives, should suffice to avert perspectivism-cum-conceptual relativism in relation to scientific instruments.

Daston and Galison (2007) identify four types of objectivity, each *predominant* in different periods, though each relevant to other notions of objectivity over considerably longer periods of time past their predominance. Truth-to-nature, the first standard of objectivity identified by Daston and Galison (2007), was predominant in the 17th and 18th century. It consisted in identifying idealised types – which were arrived at through reasoning and selection. Idealised types could not be found in nature, but they were taken to be 'truer' to nature than any unruly token. Tokens had fleeting features which had to be brought within an objective type through selection, synthesis, and idealisation. To the 17th and 18th century naturalists' 'unreasoned observations' were considered subjective, whilst the "idea in the observation" and not the observation itself was considered objective, true-to-nature.

The truth-to-nature image of objectivity changed around 1830, giving way to mechanical objectivity which regulated scientific practice for nearly a century. New means of mechanisation and automation promised deliverances of instruments, such as photographic images, uncontaminated by the dangerous distortions of reasoned images. When automation was not possible, exceedingly proceduralized means of recording nature without distortion or interpretation were developed, which often involved "humans acting as will-less machines" (p. 120). Yet, no automated instruments could offer 'pure', unadulterated access to nature. For example, depth of field or colour, could not be precisely recorded by automatic means, leading to accuracy being traded off for mechanical reproduction. The preponderance of such trade-offs, despite automation, left an ineliminable human element which the succeeding image of objectivity, structural objectivity, sought to suppress.

Structural objectivity emerged in the 1880s, co-existed with mechanical objectivity till at least the 1930s, and is still embraced by scientists and philosophers with a structuralist bent today. Structural objectivity, which must be "communicable to all" and according to which the “private mental world of individual subjectivity” (p. 254) has no place in the epistemology of nature, is not always applicable to instruments, except maybe for logic devices such as counters, spark chambers, and wire chambers (see Galison 1997 for more details on the tradition of logic devices). This is because, structural objectivity is primarily concerned with “enduring structural relationships that survived mathematical transformations, scientific revolutions, shifts of linguistic perspective, cultural diversity, psychological evolution, the vagaries of history, and the quirks of individual physiology” (p. 259), and not, strictly speaking, with the deliverances of instruments. Whilst not pertaining directly to instruments, structural objectivity is worth bringing into the present discussion for it was concurrent with mechanical objectivity and it neither occurred nor shifted concomitantly to broad perspectives.

Structural objectivity proved insufficiently versatile for understanding complex families of phenomena and thus a new form of objectivity, in the form of trained judgment, became predominant between mid- to late twentieth century. Trained judgment was needed to “synthesise, highlight, and grasp relationships” and to “smooth, refine, or classify images” (p. 314). In stark contrast with both mechanical objectivity and structural objectivity, which sought to extirpate individual judgment, trained judgement relied on an individual’s ability to “read, to interpret, to draw salient, significant structures from the morass of uninteresting artifact and background” (p. 328). Trained judgment relied on the human ability to ‘seize pattern’ and to obtain ‘knowledge at a glance’, skills that were “acquired through a sophisticated apprenticeship” (p. 331). Interpretation, previously conceived as epistemically problematic and as stunting the effort to ‘get at the world’, was now conceived as necessary to interpret ever more complex images produced by sophisticated instruments.

Thus, as the history of objectivity distinctly indicates, there is no abrupt shift from one standard of objectivity to the next. In fact, two or more standards of objectivity survive alongside one another, whilst the transition from one standard to another is clearly traceable. Unlike the traditional Kuhnian narrative of wholesale paradigm-changes, shifts in objectivity standards are not wholesale. Not only does each type of objectivity safeguard against specific types of subjectivity and thus screens off epistemic threats such as “drowning in details, of burking a fact to support a theory, of being straitjacketed by mechanical procedures” (p. 377), all of which are “genuine dangers to knowledge” (id.). But, each objectivity standard builds on and reacts to earlier specific threats to knowledge. Therefore, as Daston and Galison (2007) suggest, it “is a misconception, albeit an entrenched one, that historicism and relativism stride hand in hand” (p. 376).

If one accepts Daston and Galison’s (2007) history of objectivity, another important observation becomes salient: objectivity shifts do not correspond to shifts in broad perspectives. For example, Lorentzian ether theory and special relativity can both be said to be governed by structural objectivity, despite being different broad perspectives (for the history of special relativity and Lorentzian ether theory, see Brown 2005). Similarly, trained judgment governed cloud chamber experiments both prior to and post the crystallisation of relativistic quantum mechanics (Creţu 2020a, Roqué 1997). Scientists, in such cases, successfully navigated not only shifts in broad perspectives but also later shifts in objectivity standards (Galison 1997). What the history of objectivity demonstrates is that conceptual relativism can be avoided as long as shifts in objectivity (a). are not abrupt and discontinuous and (b). do not correspond to shifts in broad perspectives. Thus, knowledge derived from scientific instruments can be objective despite changes in broad perspectives.

What if broad perspectives are broader?[15] That is, what if the objectivity standards themselves define the perspectives, and when they shift, the instruments and their deliverances also shift? To be clear, the critic may insist that the objectivity led response leaves open the possibility that instrumental incommensurability occurs when objectivity standards shift. Drawing on Galison (1997) and Hacking (1983), who have presented detailed case studies involving instrument led continuity despite changes in theory, a novel answer that demonstrates instrument led continuity despite changes in objectivity standards is offered in the next section.

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[15] Thanks to Nicos Stylianou for very useful discussions on this issues and for pushing me to clarify this point.

3.3 Instrument Led Response

The second response to instrumental incommensurability resides in the fact that instruments and their outputs typically do not change when objectivity standards change. To be clear, the claim is that when objectivity standards shift, scientists who adhere to the new predominant standard can nevertheless use instruments designed according to previous objectivity standards. Importantly, the outcomes of such instruments are not typically contested either. This is not to say that in some cases instruments and their datum may not lose their original significance or the datum may not be interpreted differently. This can of course occur, but typically, the datum stays the same.[16] To illustrate this claim, let us consider two brief examples.

The first example, drawn from physics, is primed to illustrate the fact that instruments and their deliverances can be markedly cross-perspectival, even when perspectives are defined by the objectivity norms themselves. That is, despite being built or used to deliver data under the auspices of one standard of objectivity, the instrument and the data produced, often successfully survive shifts in objectivity standards. The cloud chamber, constitutes one example of an instrument spanning a lengthy and versatile career through shifting objectivity standards. The cloud chamber is undoubtedly one of the most important instruments of the 20th century.[17] It played an important role in many Nobel Prizes in Physics and it gave rise to the tradition of 'golden events' – that is, the tradition of making visible and capturing on film the interactions of sub-atomic phenomena.[18]

The cloud chamber was invented by C.T.R. Wilson in 1911 under the patronage of mechanical objectivity. Whilst pursuing research in atmospheric phenomena, Wilson recorded the first golden event, of an alpha ray, in 1911. The cloud chamber, though developed by Wilson for the study of atmospheric phenomena, was soon appropriated by the Cavendish physicists to study sub-atomic phenomena. After a series of tweaks and

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[16] Ackerman (1985), for example, notes that "[w]hen our theories change, we may conceive of the significance of the instrument and the world with which it is interacting differently, and the datum of an instrument reading may change in significance, but the datum can nonetheless stay the same, and will typically be expected to do so." (p. 33).

[17] The historical details regarding the cloud chamber are primarily drawn from Galison (1997), Das Gupta and Ghosh (1946), and Blackett (1960).

[18] See Staley (1999) on golden events and a criticism of Galison (1997).

improvements, the cloud chamber gave rise to further golden events, such as the photograph of the positron published by Carl D. Anderson in 1932 and the joint discovery of the muon by Anderson and Seth H. Neddermeyer in 1936. The tradition of golden events, inaugurated by C.T.R. Wilson under the auspices of mechanical objectivity, gathered momentum under the patronage of trained judgment with Anderson's discovery of the positron, and it is still very much alive almost a century later, and in spite of various changes in standards of objectivity. Importantly, neither C. T. R. Wilson's photograph of alpha rays, nor Carl Anderson's photograph of the positron have lost their significance, nor have Wilson's cloud chamber or Anderson's cognate apparatus been called into question. These photographs were produced from the vantage point of perspectives governed by standards of objectivity different from the standards which originally governed the invention of the cloud chamber and were embedded within successive broad perspectives governed by yet different norms of objectivity. Thus, what we can learn from the history of the cloud chamber is that changes in objectivity have not transformed or denied the significance of either the cloud chamber itself or of its capacity to produce golden events. To put it differently, its ladeness to different norms of objectivity did not bring about conceptual relativism via instrumental incommensurability. On the contrary, it is clear that the use and importance of the cloud chamber cuts across both broad perspectives and changing objectivity standards, and it is thus markedly cross-perspectival.

The second example, drawn from astrophysics, focusses on the data, rather than the instruments per se. It purports to show that even when certain instruments become obsolete, their deliverances retain their original authority despite shifts in objectivity standards. The example concerns the photographic plates of the spectra of stars that became available towards the end of the 19th century with the invention of the spectroscope.[19] By attaching a prism or a slit to a telescope to separate the rays of starlight by their wavelength, their unique spectra or absorption lines can be recorded and their brightness can thus be measured. The first successful attempt to photograph the spectra of stars belongs to Henry Draper, who photographed the spectrum of Vega in 1872, with similar

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[19] Unless otherwise indicated, the historical details pertaining to this example are drawn from Hoffleit (1991).

research also being conducted by William and Margaret Huggins.

Henry Draper's photographic plates were analysed and measured by Edward C. Pickering at the Harvard Observatory and constituted the catalyst for the creation of the Henry Draper Memorial which gave rise to the Draper Catalogue of Stellar Spectra, first published in 1890 by Pickering and Williamina Fleming, with subsequent instalments in 1897 from Antonia Maury, and in 1901 from Annie Jump Cannon. The Draper Catalogue of Stellar Spectra constitutes the first modern classification of stars and is the forerunner of both The Henry Draper Catalogue (published between 1918 and 1924 by Annie Jump Cannon) [20] and of Morgan, Keenan, and Kellman's 1943 Atlas of Stellar Spectra.

Importantly, for our purposes, the Henry Draper Catalogue was designed according to the canons of mechanical objectivity, whereas the Morgan, Keenan, and Kellman's Atlas of Stellar Spectra relied on trained judgement. Yet despite the use of mechanical objectivity, the results of the Henry Draper Catalogue were not only fully understood and recognised by their successor, but the spectrographic photographs on which it was based preserved, in bulk, their significance. Although Morgan, Keenan, and Kellman used different instruments, published new photographs, and operated with a distinct norm of objectivity, i.e., trained judgment, they cite the Draper Catalogue as the direct forerunner of their own classification (see Morgan et al. 1943 and Daston and Galison 2007 for details). The spectrographic photographs which constitute the basis of the Henry Draper Catalogue of Stellar Spectra can thus be said to cut across shifting objectivity standards. What this example suggests then is that changes in objectivity standards did not lead to conceptual relativism brought about by instrumental incommensurability.

Two examples cannot conclusively show that instrumental incommensurability cannot occur or that it does not lead to conceptual relativism when objectivity standards shift. Reflecting on these examples suggests nevertheless that conceptual relativism can be avoided when instruments and their deliverances survive shifts in objectivity standards. Moreover, conceptual relativism via instrumental incommensurability can also be avoided

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[20] Two separate extensions have been published as well, the Henry Draper Extension, published between 1925 and 1936, and the Henry Draper Extension Charts, first published in 1937, work on both being undertaken by Annie Jump Cannon and her assistant, Margaret Mayall.

when shifts in broad perspectives do not correspond to objectivity standards shifts. Thus, instead of constituting a novel epistemic challenge, the dependence of instruments on broad perspectives, when closely analysed, provides instead the means to mount a novel response to the old epistemic challenge of conceptual relativism.

To sum up, it was shown that not only are objectivity standards and broad perspectives not concomitantly shifting, but instruments and their deliverances can cut across both broad perspectives and objectivity standards. So whilst objectivity standards and instruments are in some respects perspectival, by being historically and intellectually situated both within and outside broad perspectives, they are equally cross-perspectival. Thus, the scientific instruments themselves, and the objectivity standards governing them, equally constitute tools to block conceptual relativism brought about by instrumental incommensurability.

4 Narrow Perspectives

This section examines the nature of the dependence of instruments on 'narrow perspectives', the resulting problem(s), and a potential solution. Narrow perspectives, unlike broad perspectives, have a significantly restricted scope, yet they are not restricted to a single theory or model. Narrow perspectives are distinctively *perspectives or points of view*, unrestricted to any particular theory (Creţu 2020a) or just to theory (Massimi 2012). Narrow perspectives can be understood as "sophisticated theoretical framework[s] that encompasses the set of theoretical interests and background theoretical knowledge (principles and assumptions equally) that a researcher or group of researchers can be said to hold at any given time" (Creţu 2020a, p. 29). Or a narrow perspective can be constituted by as a scientist's epistemic perspective which includes beliefs about the phenomena under investigation, the correct functioning of instruments and the validation of their outputs, but also more general beliefs about their "perceptual system, cognitive faculties, measurement devices, and their reliability as sources of belief" (Massimi 2012, p. 41). Either notion of perspective characterises the working stance of a scientist, who, in one capacity or another, comes to have a bearing on scientific instruments, directly by using them, or indirectly by affecting the data. Since scientific instruments can become thus laden to a scientist's (narrow) perspective, elucidating the nature of the ensuing ladeness will prove highly instructive.

4.1 Instrumental Theory-Ladeness

Scientific instruments may become laden to a scientists's viewpoint in a variety of ways. In the first instance, theory ladeness can occur in cases where the theory governing the instrument and the theory of the phenomena are one and the same. Second, theory-ladeness and practical problems therewith can survene either as a result of an over-attachment to the theory that clashes with the discordant data, or can be due to practical problems of theory ladeness such as "experimental design, failure to interpret observations correctly, possible experimenter bias, and difficulties in data acquisition" (Franklin 2015, p. 155).

In the first instance, theory ladeness is avoided by making sure that the theory governing the instrument and the theory of the phenomena are different. As Franklin argues, "no obvious problems arise for the testing of the theory of the phenomena" in such cases (Franklin 2015, fn. 8, p. 439). And, even in cases in which the theory governing the instrument and the theory of the phenomena partially overlap or overlap to a large extent, successful strategies for overcoming vicious circularity have already been suggested by the New Experimentalists. For example, as early as three decades ago, Franklin et al. (1989) discussed the possibility of using an instrument whose operation depends on the same hypothesis as that of the phenomena under test and suggested that in such cases the calibration of the instrument should suffice to mitigate the threat of vicious theory ladeness. The instrument under test would be independently calibrated against an already validated instrument, by measuring a different phenomena whose theory overlaps with neither instrument. Later, Chalmers (2003) offered a detailed case study of the electron microscope, showing that in spite of a deep theory-ladeness, instruments could nevertheless be used to collect data about a phenomena, even in cases where the theory of the phenomena was involved in the use of the instrument. As Chalmers notes, "[t]he interdependence of theory and data [...] can, in appropriate circumstances, be exploited in a way that confounds rather than aids the sceptic" (p. 494). Recently, Beauchemin (2017) showed that in the cases of conglomerate instruments such as the ATLAS detector at the LHC, theory input may be essential to confer epistemic value to certain measurements.[21] In fact, "theory-ladeness of measurement is necessary for [measurements] to constitute observations" (p. 309), and often, progress in high energy physics can only be made by mutually adjusting theory and experiment. What these authors show at length is that regardless of how multiply perspectival the process of using instruments can become – from using a thermometer, to using an electron microscope, to conglomerate instruments such as the ATLAS detector at the LHC – there are epistemic strategies for avoiding vicious theory ladeness. Insofar as such epistemic strategies can be deployed, instruments remain an objective source of knowledge about the world.

In the second instance, at least one of the reasons which leads to theory-ladeness, the over-attachment to the theory that clashes with the discordant data, can be better explained in terms of scientists' (narrow) perspectives. Scientists' (narrow) perspectives will typically play an important role in accepting new data or in discarding it. For example, if the data is unexpected, "scientists with different perspectives may respond differentially to the same empirical knowledge,[...] impeding [the] authentication" of some hitherto unknown phenomena (Creţu 2020a, p. 2) and leading to disagreement. In such cases, regardless of the route taken to resolve the disagreement, scientists' (narrow) perspectives inadvertently affect the instruments and their outputs. Moreover, since narrow perspectives can encompass elements of different theories the resulting ladeness may manifest in more intricate ways. After all, instruments are not only dependent on a theory, but they are also embedded within experiments, and experiments themselves can be theory-laden in a variety of ways, as was recently argued, in different ways, by Karaca (2013) and Schindler (2013); see also Franklin and Perovic 2019 for a recent overview of these issues.

An additional reason to think that an instrument's dependence on a narrow perspective is distinct and possibly more complex than theory-ladeness consists in the potential of an instrument to produce data which can overthrow a particular theory (see Franklin

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[21] Thanks Antonis Antoniou for suggesting pointing me to Beauchemin's work.

and Perovic 2019 for more details).[22] Since the instruments themselves may be recast in a different light depending on how the data is received, let us call this instrumental theory-ladeness. In the next and final section, a solution to instrumental theory-ladeness is proposed.

4.2 Perspectivity Led Response

It was suggested that narrow perspectives contain within them elements that may engender instrumental theory-ladeness. But, since narrow perspectives are restricted neither to one theory not just to theory, they also contain justificatory tools to render instruments and their data valid and objective. It is thus clear, that narrow perspectives have a two-edged blade. Whilst their potential for engendering instrumental theory ladeness has been made clear in the previous section, let us also expose their positive features.

Narrow perspectives can encompass both entrenched background assumptions, as well as less entrenched ones pertaining to particular problems salient to working scientists (Creţu 2020a, p. 32). Furthermore, narrow perspectives enable scientists to "self-reflect on [their] beliefs, on the sources of [their] beliefs, the way beliefs cohere with one another, no less than the way in which they, individually and jointly, are anchored to the empirical ground via reliable methods" (Massimi 2012, p. 49). Thus, narrow perspectives, unlike broad perspectives, embed richer, more specific resources for justifying why we have good reasons to use a particular instrument, why the instrument is working properly, and why the data it delivers is reliable. And, they can embed distinctively non-perspectival epistemic strategies to overcome instrumental theory-ladeness that are neither specific to a broad perspective, nor governed by specific objectivity standards, but which instead are more broadly embedded within the epistemology of science.

Riches of such epistemic strategies, some directly pertaining to instruments, some pertaining more generally to experiment (and only indirectly pertaining to instruments, have been identified and discussed by the New Experimentalists Hacking (1983), Franklin (1990; 1986), Mayo (1996), Chalmers (2003), Karaca (2013). A list of such strategies

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[22] It is doubtful that an instrument or its data also have the potential to overthrow a broad perspective or an objectivity standard, or even a narrow perspective in fact.

provided by Franklin (1989) contains: i) experimental checks and calibration in which the apparatus reproduces known phenomena to reproducing artifacts that are known in advance to be present; ii) intervention, in which the experimenter manipulates the object under observation; iii) independent confirmation using different experiments; iv) elimination of plausible sources of errors and alternative explanations of the result; v) using the results themselves to argue for their validity; vi) using an independently well-corroborated theory of the phenomena to explain the results; vii) using an apparatus based on a well-corroborated theory; viii) using statistical arguments. Whilst such strategies do no entirely eliminate the threat of instrumental theory-ladeness, they go a long way in safeguarding instruments and their deliverances against this threat. And importantly, such strategies ensure that instruments can deliver apersepctival knowledge about the world.

To sum up, in this section it has been shown that narrow perspectives have a dual nature in that they can both undermine and vindicate instruments and their deliverances, and the knowledge engendered within them.

5 Conclusion and Prospectus

It is not uncommon for philosophical views to overreach. For better or worse, that is also the predicament of perspectivism, whose intuitive appeal has gained the view as many supporters as detractors. Beyond the intuitive appeal of perspectivism, questions of epistemic novelty and fruitfulness must take precedence. Yet the novelty of a claim, or lack thereof, can only be established through careful analysis, which, more often than not, may lead to surprising consequences. For example, the present analysis proceeded from a diagnosis of the epistemic unfruitfulness of the claim that ‘instruments are perspectival’ to an epistemically fruitful investigation with instruments at the fore. The instruments first approach, moved from a predictable diagnosis to extending the reach of perspectivism in surprising ways which honour the spirit, if not the letter of this increasingly popular view.

In keeping with one of the core tenets of perspectivism, forays into the history of science – through the scholarship on objectivity and the history of canonical instruments (i.e., the cloud chamber) – disclosed previously untapped resources for resolving well known problems. And, in line with the second tenet of perspectivism, instruments have been restored to their function of giving us knowledge about the world. Yet as scientific practice becomes increasingly dominated by one instrument – the digital computer – new questions lay ahead.

A compelling avenue for future research is to investigate the degree to which the described solutions bear out in realms of science increasingly dominated by the digital computer. Such a task would require, amongst other things, an extension of the scholarship on objectivity, the identification of clear cut cases where the digital computer acts as an instrument, as well as a better understanding of the relationship between digital computers and broad and narrow perspectives. Further, it would be important to determine whether the digital computer is a natural extension of traditional instruments, leading to the same problems, to which the same solutions apply. Or, whether new problems and solutions might require an even finer grain of perspectivism.[23]

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[23] The versatility of the digital computer (Parker 2010) is indicated by the fact that it can be involved not only in data production, but also in data analysis or the set-up of an experiment. Equally relevant is the complexity of computer simulations (Morgan and Morrison 1999, Humphreys 2004, Winsberg 2010, Morrison 2015).

References

Ackerman, R. J. (1985). *Data, Instruments, and Theory. A Dialectical Approach to Understanding Science*. Princeton University Press.

Baghramian, M. and Carter, J. A. (2019). Relativism. In Zalta, E. N., editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University, winter 2019 edition.

Baird, D. (2004). *Thing knowledge: A philosophy of scientific instruments*. University of California Press.

Beauchemin, P.-H. (2017). Autopsy of measurements with the ATLAS detector at the LHC. *Synthese*, 194(2):275–312.

Blackett, P. M. S. (1960). Charles Thomson Rees Wilson, 1869-1959. *Biographical Memoirs of Fellows of the Royal Society*, https://royalsocietypublishing.org/doi/10.1098/rsbm.1960.0037:269–295.

Brenni, P. (2013). From workshop to the factory: the evolution of the instrument-making industry, 1850-1930. In Buchwald, J. Z. and Fox, R., editors, *The Oxford Handbook of the History of Physics*, pages 584–650. Oxford University Press.

Brown, H. R. (2005). *Physical Relativity. Spece-time structure from a dynamical persepctive*. Clarendon Press Oxford.

Chakravartty, A. (2010). Perspectivism, inconsistent models, and contrastive explanation. *Studies in History and Philosophy of Science Part A*, 41(4):405–412.

Chakravartty, A. (2017). *Scientific ontology: Integrating naturalized metaphysics and voluntarist epistemology*. Oxford University Press.

Chalmers, A. (2003). The theory-dependence of the use of instruments in science. *Philosophy of Science*, 70(3):493–509.

Chirimuuta, M. (2016). Vision, perspectivism, and haptic realism. *Philosophy of Science*, 83:746–746.

Creţu, A. (2020a). Diagnosing disagreements: The authentication of the positron 1931-1934. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*.

Creţu, A. (2020b). *Natural Kinds as Real Patterns: Or How to Solve the Commitment Problem for Perspectival Realism*. http://philsci-archive.pitt.edu/16828/.

Creţu, A. (2020c). Perspectival realism. In Peters, M., editor, *Encyclopedia of Educational Philosophy and Theory*. Springer, Singapore.

Das Gupta, N. and Ghosh, S. (1946). A report on the Wilson cloud chamber and its applications in physics. *Reviews of Modern Physics*, 18(2):225.

Daston, L. and Galison, P. (2007). *Objectivity*. Zone Books. New York, 2010 (paperback) edition.

Evans, P. W. (2020). Perspectival objectivity. Or: how I learned to stop worrying and love observer-dependent reality. *European Journal for Philosophy of Science*, 10(2):1–21.

Franklin, A. (1986). *The Neglect of Experiment*. Cambridge University Press, first paperback edition 1989 edition.

Franklin, A. (1989). The epistemology of experiment. In Gooding, D., Pinch, T., and Schaffer, S., editors, *The Uses of Experiment*, pages 437–460. Cambridge University Press.

Franklin, A. (1990). *Experiment, right or wrong*. Cambridge University Press, online 2009 edition.

Franklin, A. (2015). The theory-ladenness of experiment. *Journal for general philosophy of science*, 46:155–166.

Franklin, A., Anderson, M., and et. al. (1989). Can a theory-laden observation test the theory? *British Journal for the Philosophy of Science*, 40:229–231.

Franklin, A. and Perovic, S. (2019). Experiment in physics. In Edward N. Zalta, editor, *Standford Encyclopeadia of Philosophy*. Metaphysics Research Lab, Stanford University, https://plato.stanford.edu/archives/win2019/entries/physics-experiment/, 2019 winter edition edition.

Galison, P. (1997). *Image and logic: A material culture of microphysics*. University of Chicago Press.

Giere, R. (2000). The perspectival nature of scientific observation. *https://www.philsci.org/archives/psa2000/perspectival-nature.pdf*, first accessed March 3rd 2020.

Giere, R. N. (1999). *Science without laws*. University of Chicago Press.

Giere, R. N. (2006). *Scientific Perspectivism*. University of Chicago Press, paperback edition 2010 edition.

Giere, R. N. (2013). Kuhn as perspectival realist. *Topoi*, 32(1):53–57.

Hacking, I. (1983). *Representing and intervening*. Cambridge University Press Cambridge.

Hackman, W. D. (1989). Scientific instruments: Models of brass and aids to discovery. In David, G., Pinch, T., and Schaffer, S., editors, *The uses of experiment*, pages 31–65. Cambridge University Press.

Hanson, N. R. (1958). *Patterns of discovery: An inquiry into the conceptual foundations of science*. CUP Archive.

Heidelberger, M. (2003). Theory-ladenness and scientific instruments in experimentation. In Radder, H., editor, *The Philosophy of Scientific Experimentation*, pages 138–151. University of Pittsburgh Press.

Hicks, M. (2017). *Programmed Inequality. How Britain Discarded Women Technologists and Lost Its Edge in Computing*. MIT Press, first mit press paperback edition, 2018 edition.

Hoffleit, D. (1991). The evolution of the Henry Draper Memorial. *Vistas in Astronomy*, 34:107–162.

Humphreys, P. (2004). *Extending ourselves: Computational science, empiricism, and scientific method*. Oxford University Press.

Karaca, K. (2013). The strong and weak senses of theory-ladenness of experimentation: Theory-driven versus exploratory experiments in the history of high-energy particle physics. *Science in Context*, 26(1):93–136.

Kuhn, T. (1962). *The Structure of Scientific Revolutions*. Chicago University Press.

Laudan, L. (1977). *Progress and its Problems: Towards a theory of scientific growth*. University of California Press of California Press, 1978 edition.

Laudan, L. (1990). *Science and Relativism: Some Key Controversies in the Philosophy of Science*. The University of Chicago Press.

Lauwerys, J. A. (1937). Scientific instruments. *Proceedings of the Aristotelian Society*, 38:217–240.

Massimi, M. (2012). Scientific perspectivism and its foes. *Philosophica*, 84(1):25–52.

Massimi, M. (2018a). Four kinds of perspectival truth. *Philosophy and Phenomenological Research*, 96(2):342 – 359.

Massimi, M. (2018b). Perspectival modeling. *Philosophy of Science*, 85(3):335–359.

Massimi, M. (2018c). Perspectivism. In Saatsi, J., editor, *The Routledge Handbook of Scientific Realism*, chapter 13, pages 164 – 175. Routledge.

Massimi, M. (2018d). Points of view: Kant on perspectival knowledge. *Synthese*, pages 1–18.

Mayo, D. G. (1996). *Error and the growth of experimental knowledge.* University of Chicago Press.

McConnell, A. (2013). Instruments and instrument-makers, 1700–1850. In Buchwald, J. Z. and Fox, R., editors, *The Oxford Handbook of the History of Physics*, pages 326–357. Oxford University Press.

Morgan, M. S. and Morrison, M. (1999). *Models as Mediators.* Cambridge University Press.

Morgan, W., Keenan, P. C., and Kellman, E. (1943). *An atlas of stellar spectra.* University of Chicago Press, $https : //ned.ipac.caltech.edu/level5/ASS_Atlas/frames.html$.

Morrison, M. (2011). One phenomenon, many models: Inconsistency and complementarity. *Studies in History and Philosophy of Science Part A*, 42(2):342–351.

Morrison, M. (2015). *Reconstructing reality: Models, mathematics, and simulations.* Oxford Studies in Philosophy of Science.

Parker, W. S. (2010). An instrument for what? Digital computers, simulation and scientific practice. *Spontaneous Generations: A Journal for the History and Philosophy of Science*, 4(1):39–44.

Roqué, X. (1997). The manufacture of the positron. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 28(1):73–129.

Schindler, S. (2013). Theory-laden experimentation. *Studies in History and Philosophy of Science Part A*, 44(1):89–101.

Staley, K. W. (1999). Golden events and statistics: What's wrong with galison's image/logic distinction? *Perspectives on Science*, 7(2):196–230.

Turner, A. (2013). Physics and the instrument-makers, 1550–1700. In Buchwald, J. Z. and Fox, R., editors, *The Oxford Handbook of the History of Physics*, pages 96–108. Oxford University Press.

Winsberg, E. (2010). *Science in the age of computer simulation.* University of Chicago Press.