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# Theoretical Virtues, Truth, and the Epistemic Aim of Scientific Theorizing

Mousa Mohammadian[1]*

[1]Department of Philosophy, American University of Beirut, Beirut, Lebanon

**Corresponding author*: mm377@aub.edu.lb

## Abstract

I argue that the epistemic aim of scientific theorizing (EAST) is producing theories with the highest possible number and degree of theoretical virtues (call this "TV-EAST"). I trace TV-EAST's logical empiricist origins and discuss its close connections to Kuhn's and Laudan's problem-solving accounts of the aim of science. Despite TV-EAST's antirealist roots, I argue that if one adopts the realist view that EAST is finding true theories, one should also endorse TV-EAST. I then defend TV-EAST by showing that it addresses the challenges raised against using the "aim of science" metaphor and offers significant advantages over the realist account.

## 1. Introduction

There are some characteristics that are commonly viewed as good, desirable, and valuable for scientific theories such that a theory that instantiates more and higher degree of them is, *ceteris paribus*, better than its rival. These desiderata, known as theoretical virtues,[1] include the following. *Empirical fit* is about a theory's conformity with the available data. *Accuracy* refers to the tightness of (usually quantitative) fit between a theory and data. Two equally empirically fit theories might differ vis-à-vis their accuracy even though two equally accurate theories in range and degree are both equally empirically fit. *Predictive power* is a theory's ability to predict testable phenomena. *Internal consistency* is being free from logical or mathematical inconsistencies. *External consistency* is a theory's consistency with well-established scientific theories. This consistency can be merely logical but higher degrees of

[1] Theoretical virtues are also known as epistemic values and cognitive values. I use "theoretical virtues" broadly, which includes empirical and nonempirical virtues. Norton (2021, ch. 5) argues against calling these desiderata "virtues" or "values" (cf. Mohammadian 2022). Because this terminology is widely used in the literature, I also use it in this article.

external consistency can be obtained as well when, for instance, a theory explains a well-established theory or is explained by it. *Explanatory power* is a theory's ability to provide causal, mechanistic, or nomological explanation for a phenomenon of interest. *Simplicity* includes syntactic simplicity, which "measures the number and conciseness of the theory's basic principles," and ontological simplicity, which "measures the number of kinds of entities postulated by the theory" (Baker 2022). *Non–ad hocness* is being free of modifications that are simply introduced to save a theory from refutation without adding to its empirical content. *Unification* is a theory's ability to "unify, under a single framework, laws, phenomena or classes of facts originally thought to be theoretically independent of one another" (Morrison 2000, 2). *Fruitfulness* is a theory's ability to provide scientists with ideas for further research and promises of future developments. And *broad scope* pertains to the size of the domain of phenomena that is covered by a theory.[2]

My goal in this article is to revive (or at least bring back into the focus) an account of the Epistemic Aim of Scientific Theorizing (EAST) that I call the Theoretical Virtues as Epistemic Aim of Scientific Theorizing (TV-EAST, for short). According to TV-EAST, EAST is producing theories with *the highest possible number and the highest possible degree of theoretical virtues*. Although this account is not among the current major contenders of EAST (i.e., problem solving, truth, knowledge, and understanding), I argue that it has considerable merits. In section 2, I clarify my uses of "epistemic" and "theorizing" and their resulted limitations in TV-EAST's application. Section 3 discusses the history of TV-EAST, emphasizing three aspects: its logical empiricist origin, interactions with Kuhn's and Laudan's problem-solving accounts, and association with antirealism. Section 4 dissociates TV-EAST from antirealism and shows its compatibility with scientific realism. I argue that if one adopts the truth or the realist account of EAST (henceforth, Truth-EAST), namely, that science aims at finding true theories, one should commit to TV-EAST as well. Section 5 defends TV-EAST by showing that it successfully addresses the challenges raised against using the metaphor of "the aim of science" and has important advantages over Truth-EAST.

[2] Different catalogs of theoretical virtues offered in the literature have *considerable* overlaps (Hempel 1966, 1983b; Quine and Ullian 1978; Kuhn 1977; Newton-Smith 1981, 226–32; McMullin 1996, 2008; Lacey 1999; Lycan 1985; Douglas 2013; Keas 2018) and, more interestingly, they have not changed much in the history of modern science. For instance, almost all the previously mentioned desiderata can be found in Robert Boyle's "Notes on a Good and an Excellent Hypothesis" (1991, 119) from the seventeenth century and Peirce's works from the nineteenth century (Mohammadian 2019).

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## 2. Preliminary remarks

First, in the literature on the aim of science and theoretical virtues, "epistemic" appears, usually without clarification, in at least three senses:

I. "Epistemic" as truth-related: An aim or a virtue is epistemic if it simply pertains to the truth (or falsity) of a theory (Laudan 2004).

II. "Epistemic" as knowledge related: An aim or a virtue is epistemic if it pertains to the production of knowledge or true justified belief, either by promoting truth or offering justification for theoretical decision makings (McMullin 1984b; Bird 2022, ch. 2).

III. "Epistemic" as understanding related: An aim or a virtue is epistemic if it promotes our understanding of the world (Longino 2008; Potochnik 2025). Because understanding is attained by a knowing subject, the epistemic status of an aim or a virtue is relevant to *our* cognitive abilities (Churchland 1985) and the intelligibility of theories for *us* (de Regt 2009). Some have used "cognitive" rather than "epistemic" in this context (Laudan 2004; Douglas 2013).

In this article, I use "epistemic" broadly, which includes all these senses. Although in contemporary analytic epistemology "epistemic" primarily indicates truth related or knowledge related, its use in understanding-related sense goes back to Aristotle (Burnyeat 2012) and its broad use is now common in philosophy of science literature (see also Dorato 2004; de Regt 2009, 2017; Potochnik 2017).

Regarding theoretical virtues, whether a virtue is strictly epistemic (as *per* I-II) or just cognitive (as *per* III) is a matter of disagreement and largely a function of whether one is a realist or an antirealist. The consistency of TV-EAST as an account of the epistemic aim of scientific theorizing in terms of theoretical virtues requires a consistent use of "epistemic" for *theoretical virtues* and the *aim of scientific theorizing*. This condition is satisfied in my discussions. For, as I shall show, many realists hold that *cognitive* theoretical virtues are truth conducive and hence *epistemic* (as *per* I-II). This makes considering these *cognitive* virtues as constitutive of the *epistemic* aim of scientific theorizing unproblematic within the realist frameworks. Moreover, many antirealists who deny the epistemicity (as *per* I-II) of *cognitive* theoretical virtues also deny that *when it comes to unobservables*, truth is an epistemic aim of scientific theorizing. Yet, as I shall show, they generally admit that cognitive virtues are

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constitutive of the aim of scientific theorizing. Thus, within the antirealist frameworks, too, "epistemic" is consistently used for theoretical virtues and the aim of scientific theorizing.

Second, many realists and antirealists (van Fraassen [1980] is a notable exception) hold that being merely "cognitive" does not necessarily make a virtue less valuable than epistemic (as *per* I-II) virtues. Some (Churchland 1985; Laudan 2004) even argue that at least some cognitive virtues are generally more valuable than epistemic virtues. This implies that for these philosophers, cognitive virtues are not merely instruments for attaining epistemic virtues because an instrument cannot be more valuable than an aim. In line with these philosophers, Mohammadian (2021) argues that if some theoretical virtues are constituents of EAST and scientific rationality is instrumental, dividing theoretical virtues into means and aims results in insurmountable problems regarding scientific rationality and progress. I adopt this approach here which sets an important limitation on TV-EAST. As I shall argue later, one advantage of TV-EAST over Truth-EAST is that it is a common core upon which many realists and nonrealists can agree. But, unlike many other antirealists, a traditional constructive empiricist such as van Fraassen (1980) would not accept TV-EAST as a common core.[3]

Third, it should be noted that arguments against dividing theoretical virtues into means and aims do not imply that all theoretical virtues should be valued equally. Rather, "there may still be variation in how these values are ranked and applied in specific cases" (de Regt 2017, 38). Kuhn (1977) famously argues for the existence of trade-offs among theoretical virtues. For instance, a theory's empirical fit or explanatory power might be enhanced by compromising on its non–ad hocness (e.g., presupposing dark matter in cosmology) or its simplicity (e.g., positing the existence of the Higgs boson as a new fundamental particle).

[3] Van Fraassen (1980, 87–96) considers some theoretical virtues that he calls "pragmatic virtues" to be merely instrumental for empirical adequacy and consistency, the only genuinely epistemic virtues. His instrumental rationality, grounded in his stance epistemology and voluntarism (van Fraassen 2002), makes his position resistant to Mohammadian's (2021) challenges and hence to accepting TV-EAST as a common core. For example, van Fraassen adopts the policy that a greater degree of a pragmatic virtue such as explanatory power is *un*desirable *unless* it improves empirical adequacy:

> We may ask whether…if several theories were empirically equivalent, the one which explains most would have to be accepted. Against this idea count all the examples of scientists refusing to enlarge their theories in ways that do not yield different (or further) empirical consequences. (1980, 95)

He then calls cases of explanatory power that do not improve empirical adequacy "metaphysical extensions of the theory [that] (if indeed possible) would be philosophical playthings only" (ibid.) *even if they do not result in any less empirically adequate theories*. While one might argue that this policy is misguided, van Fraassen's voluntarism frames such disagreements as acceptable differences regarding epistemic stances.

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Matthewson and Weisberg (2009, 169) also argue that "[d]espite their best efforts, scientists may be unable to construct models that simultaneously exemplify every theoretical virtue" and identify different types of trade-offs that might arise in such cases. Furthermore, Kuhn argues that facing such trade-offs, there is no algorithm to dictate a unique choice. In a widely discussed paper, Okasha (2011) argues that it is *impossible* to have a unique algorithm for theory choice based on the rankings of different theoretical virtues. Here, I set aside the issue of trade-offs. Suffice it to say that scientists might have different verdicts about whether a theory (or which theory) instantiates or is more likely to instantiate the highest possible number and degree of theoretical virtues (see, e.g., Wolf and Duerr 2024; Duerr and Fischer [forthcoming]). For brevity, I use "the best balance of theoretical virtues" instead of "the highest possible number and the highest possible degree of theoretical virtues" and "an impressive balance of theoretical virtues" instead of "impressive number and impressive degree of theoretical virtues."

Finally, in this article, I only focus on one particular, though essential, scientific practice, namely, *scientific theorizing*. So, data collection, data processing, grant writing, and, to a great extent, experimentation are not within the scope of my discussion—following Hacking (1983) and Galison (1987), I *assume* that theorizing and experimentation are two separate (though related) practices. By "theorizing," I refer to two contexts: *theory choice*, in which scientists select among rival theories (e.g., Kepler choosing Copernican over Ptolemaic theory), and *theory development*, in which scientists work on an already selected theory to further develop it (e.g., Kepler replacing circular orbits with elliptical ones in Copernican theory). Furthermore, I focus on scientific theorizing as conducted primarily by human beings. Black box models generated through machine learning fall outside my scope because they rely on "methods that push humans away from the centre of the epistemological enterprise" and are not "tailored to human cognitive capacities" (Humphreys 2009, 616). Consequently, epistemic theoretical virtues relevant to human-driven scientific theorizing may not apply to theorizing conducted by machine learning.

## 3. History of TV-EAST

This section examines three aspects of TV-EAST's history relevant to my discussion. First, I explore its historical origins in the works of prominent logical empiricists, selectively focusing on themes that are later used to support TV-EAST. Second, I discuss TV-EAST's

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interactions with the problem-solving accounts of EAST, introduced by Kuhn and Laudan. Revealing their close affinity, I show that both Kuhn and Laudan adopt TV-EAST in their later works. Finally, I address the strong antirealist associations of TV-EAST, which I aim to dispel in section 4.

### 3.1. Logical empiricist origins of TV-EAST

Early explications of the idea that theoretical virtues are constitutive of EAST can be found in the works of logical empiricists. The following brief chronologically ordered discussion shows a gradual development and increasing clarity in understanding EAST in terms of theoretical virtues. A good starting point is Felix Kaufmann (1943, 273–74), who holds that theoretical virtues, or as he calls them "the theoretical ideals of inquiry such as unity, simplicity, universality, [and] exactness of knowledge" are "intrinsically related to scientific goals." Due to their intrinsic relation with the aims of science, theoretical virtues play an indispensable role in Kaufman's account of *theoretical significance* of scientific problems. Briefly, Kaufman explains that not all scientific problems are equally significant. Rather, "[p]roblems the solution of which appears to be more conducive to the promotion of these ideals are regarded as more significant" by scientists. That is, a scientific problem is theoretically more significant than others when its solution results in a better balance of theoretical virtues.

Herbert Feigl (1950, 1981) offers a slightly more developed version of TV-EAST. In "Existential Hypotheses: Realistic versus Phenomenalistic Interpretations," one of the earliest defenses of modern scientific realism against different strands of phenomenalism (e.g., positivism and operationalism), Feigl suggests different reasons for employing "theoretical construction" that go beyond what is directly observable in science. His main arguments center on the theoretical virtues that such constructions confer on scientific theories, for example, "considerable formal simplification" (1950, 38), "explanatory power," "fruitful[ness] in suggesting further avenues of research," "unification," "derivability (predictability) of *more directly* confirmable consequences," and "nomological (causal) coherence" (ibid., 39). Interestingly, however, Feigl points out that these characteristics do *not* distinguish realist interpretations of scientific theories from their phenomenalist foes. Rather, the two positions resemble one another regarding the desirability of theoretical virtues because they are constitutive of EAST and realism and phenomenalism are not two different

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ways of scientific theorizing but two different *interpretations* (existential vs. phenomenalist interpretations) of theoretical constructs.

Nagel's "The Nature and Aim of Science" (1967) offers a yet clearer explication of TV-EAST. To clarify the nature and aim of science, Nagel contrasts scientific knowledge and common-sense knowledge. The aim of scientific knowledge is to overcome the "serious limitations" of commonsense knowledge, which include impreciseness, inconsistency, being highly fragmented, having a limited range of applications, and the inability to make reliable guides in novel situations. It is not difficult to see that such limitations can be addressed by instantiating theoretical virtues such as accuracy, consistency, unification, broad scope, predictive power, and fruitfulness. Furthermore, not only are theoretical virtues constitutive of the aim of science but also they are constitutive of the epistemic nature of science: "[I]t is *a distinctive mark* of science that it deliberately attempts to produce conclusions freed from the limitations of common sense, or possessing those limitations to a lesser degree" (1967, 6; my emphasis).

The clearest explication of TV-EAST can be found in works of Hempel (1979a, 1979b, 1981), particularly in his contributions to the debate on the rationality of science following the publication of Kuhn's *The Structure of Scientific Revolutions* (1962). Hempel finds it "interesting, but also somewhat disturbing" that "Popper, Lakatos, Kuhn, Feyerabend, and others have made diverse pronouncements concerning the rationality or irrationality of science" without providing "a reasonably explicit characterization of the concept of rationality which they have in mind" (1979a, 50). Thus, he offers an instrumentalist account of scientific rationality as a general framework for this debate:

> in so far as a proposed methodological theory of science is to afford an account of scientific inquiry as a rational pursuit, it will have to specify certain aims of scientific inquiry as well as some methodological principles observed in their pursuit; finally, it will have to exhibit the instrumental rationality of the principles in relation to the goals. (Hempel 1979a, 58)

In this context, Hempel offers his construal of the aim of science in terms of theoretical virtues (or, as he calls them here, "desiderata"):[4]

[4] Hempel uses "theoretical virtues" as well (1990, 81).

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> we might plausibly conceive the goal of scientific inquiry to be the development of theories that ever better satisfy the desiderata. On this construal, the desiderata are different constituents of the goal of science rather than conceptually independent means for its attainment, and it becomes a truism that replacing a theory by a competing one that better satisfies the desiderata will constitute an improvement of scientific knowledge and will thus be a rational procedure. (Hempel 1981, 404)

To sum up, early explications of TV-EAST can be found in the works of logical empiricists. I will later return to the following important themes in these versions of TV-EAST: Theoretical virtues are determinants of the significance of theoretical problems in science (Kaufman), the desirability of the theoretical virtues as constitutive of EAST is neutral to whether one adopts realism or antirealism (Feigl), and theoretical virtues are constitutive not only of EAST but also of scientific theorizing (Nagel).

### 3.2. Theoretical virtues and the problem-solving account

Kuhn and Laudan offered what is commonly known at the problem-solving account of EAST, according to which "the aim of science is to secure theories with a high problem-solving effectiveness" (Laudan 1981b, 145; see also Kuhn 1962; Laudan 1977). In this section, I show that a proper examination of the different types of problems (or puzzles) and problem-solving activities reveals the centrality of theoretical virtues in their accounts. This analysis shows that the greatest problem-solving ability is nothing beyond the best balance of theoretical virtues, which indicates that the problem-solving account is simply TV-EAST in disguise. Moreover, I show that in their later works, both Kuhn and Laudan set this disguise aside and fully embraced TV-EAST.

Kuhn (1962) famously argues that the aim of science is problems solving but as his multiple examples show, problem solving can be always understood in terms of a theory's instantiation of theoretical virtues. Here are some of Kuhn's (ibid., ch. 3) examples of problem-solving activities and their corresponding theoretical virtues:

- Empirical fit: "to bring nature and theory into closer and closer agreement" (23).
- Accuracy and scope: "[a]ttempts to increase the accuracy and scope" (26) or "to display a new application of the paradigm or to increase the precision of an application" (30).

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- Predictive power: "[T]he use of existing theory to predict factual information of intrinsic value" (30).
- Fruitfulness: "The success of a paradigm…is at the start largely a promise of success…. Normal science consists in the actualization of that promise" (24).
- Internal consistency: providing "a logically more coherent version" of a theory (33).
- Simplicity: "[M]any of Europe's most brilliant mathematical physicists repeatedly endeavored to reformulate mechanical theory in an equivalent but logically and aesthetically more satisfying form" (33).

Due to Kuhn's construal of the aim of science as puzzle solving, it seems that Kuhn thought of theoretical virtues as methodological norms (or means) for achieving the aim of puzzle solving. Hempel (1979a) criticized this approach and suggested that Kuhn can offer a stronger account of scientific rationality if he takes theoretical virtues as constituents of EAST rather than instrumental norms. Importantly, in his response to Hempel, Kuhn accepts Hempel's view:

> [Hempel] points out that some of the difficulties with my published accounts of theory choice would be avoided if desiderata like accuracy and scope, invoked when evaluating theories, were viewed not as means to an independently specified end, like puzzle solving, but as themselves goals at which scientific inquiry aims.… Hempel's formulation is an improvement on mine. (Kuhn 1983, 564–65)

Something virtually identical can be seen in the development of Laudan's problem-solving account, both regarding the centrality of theoretical virtues in his explication of problem solving and his later embrace of TV-EAST. Laudan argues that there are two types of problems that scientists expect their theories to solve: empirical problems and conceptual problems. Empirical problems include anything that according to a theory is "in need of explanation" because it is "peculiar or "problematic" or questionable (in the literal sense of that term)" (Laudan 1977, 15). To solve an empirical problem, a theory needs to expand its domain of application to cover and explain the problematic phenomenon or provide a model that matches it to the desired degree of accuracy. That is, the theory should broaden its scope, instantiate higher degree of explanatory power, and/or better empirical fit and accuracy. Conceptual problems are of two main types (Laudan 1977, 50–54): internal conceptual problems and external conceptual problems. The former includes the internal inconsistency of

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a theory and the ambiguity of its concepts. The external conceptual problems include three types of problematic relations that a theory might have with another scientific theory: They might be logically inconsistent; they might be logically consistent but jointly implausible; or, contrary to our expectations, one of them might fail to explain (or being explained by) another. It is easy to see that solving conceptual problems can also be described in terms of exemplifying different theoretical virtues. For instance, internal conceptual problems can be solved by exemplifying internal consistency or fruitfulness by opening new avenues of research to disambiguate fundamental concepts of a theory. Consider, for instance, the concept of "gene" as the basic unit of heredity passed from parents to their offspring. Disambiguation of this concept became a fruitful research program and ended up in the development of genetics as an independent scientific discipline. To solve external conceptual problems, a theory needs to instantiate external consistency and unification. In his *Science and Values: The Aims of Science and Their Role in Scientific Debate* (1984), Laudan also acknowledges that his problem-solving account can be better formulated in terms of theoretical virtues: "an attribute will count as a cognitive value or aim if that attribute represents a property of theories which we deem to be constitutive of 'good science'" (xii).

### 3.3. Antirealism and TV-EAST

This historical overview might suggest an implicit antirealist orientation for TV-EAST. After all, most logical empiricists (apart from Feigl) as well as Kuhn and Laudan who eventually embraced TV-EAST are also united in their rejection of scientific realism. Two developments turned this *implicit* antirealist orientation into a strong association.

First, Hempel, Kuhn, and Laudan all proposed their accounts of EAST as alternatives to Truth-EAST. In his "The Irrelevance of the Concept of Truth for the Critical Appraisal of Scientific Theories" (1990), Hempel attacks the idea that science aims at "the attainment of true theories" (82) and offers "an alternative way of characterizing science as a goal-directed endeavor" (75) in which theoretical virtues are viewed "as reflecting, broadly speaking, the direction in which scientific research is headed, the objectives at which it is aiming" (77). In a similar vein, immediately after pointing out that a theory change happens only if the new theory has better problem-solving ability than its predecessors, Kuhn ties his problem-solving account to an antirealist approach about EAST: "We may…have to relinquish the notion, explicit or implicit, that changes of paradigm carry scientists and those who learn from them

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closer and closer to the truth" (1962, 170). Similarly, Laudan contrasts his problem-solving account with "a tendency to characterize the aims of science in terms of such transcendental properties as truth or apodictic certainty" and points out that a major benefit of his account is that "it assumes a goal which (unlike truth) is not intrinsically transcendent and hence closed to epistemic access" (1981b, 145). The same approach is adopted by Laudan (1984, ch. 5), where he offers TV-EAST as an alternative to Truth-EAST.

The second development was introduced by van Fraassen (1980). Following him, many adopted the idea that the realism versus antirealism debate can be understood in terms of two opposing views about the *aim* of science (see, e.g., Thagard 2004; Lyons 2005). According to realists, the aim of science is producing *true* theories while for antirealists, the aim of science is something other than truth, for example, saving the phenomena. As a result of these two developments, TV-EAST has become strongly associated with antirealism.

In the next section, I dissociate TV-EAST from antirealism. I argue that realists can adopt TV-EAST and still hold that science succeeds in finding true theories. Still stronger, I suggest that to adopt Truth-EAST, realists should aim for theories with the best balance of theoretical virtues because finding theories with an impressive balance of theoretical virtues is a requirement for attainment of true theories.

## 4. Truth as the aim of science

It is uncontroversial that scientific theories can and should be true regarding their description of observable entities and processes that can be perceived by unaided senses. But disagreements begin when it comes to a theory's claims about unobservables. Realists think that our scientific theories can truly describe unobservables while antirealists hold that (to say the least) we cannot know whether scientific theories' claims about unobservables are true. Here, my discussion focuses on the relationship between Truth-EAST and TV-EAST. Thus, without engaging in the realism versus antirealism debate, I adopt Truth-EAST and argue that it is fully consistent with TV-EAST. More specifically, I argue that realists should be committed to TV-EAST if their aim is producing true theories. Realism is a quite diverse doctrine. To make my discussion more focused, first I adopt a specific version of realism called semirealism (Chakravartty 1998, 2007, ch. 2) to lay out my arguments. Then I expand the scope of my arguments to cover some other versions of scientific realism.

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### 4.1. Detection, truth, and theoretical virtues

Semirealism distinguishes between two types of properties of unobservable entities described by scientific theories. First are *detection properties*, that is, the properties that are experimentally detected because they are causally related to our detectors through their normal behavior. This causal relation is a matter of degree. Sometimes we are just able to *detect* a property (e.g., when J. J. Thomson detected the negative charge of the electron) but sometimes we can use properties of an entity to *manipulate* other things (like using properties of electrons for electron microscopy). Second are *auxiliary properties* that are attributed by a theory to unobservables but we have not detected their causal relations with our detectors *yet*. This might have different reasons: Auxiliary properties might be fictions (dark matter might not exist), we might not know enough about the auxiliary properties to bring them into causal interaction with our instruments (as some physicists think is the case with dark matter), or we might not have a proper detector to detect them (as we could not detect the Higgs boson before building the Large Hadron Collider). Chakravartty suggests an in-principle way to make a distinction between these two types of properties:

> Detection properties are connected via causal processes to our instruments and other means of detection. One generally describes these processes in terms of mathematical equations that are or can be interpreted as describing the relations of properties…one can thus identify detection properties as those that are required to give a *minimal interpretation* of these sorts of equations. (Chakravartty 2007, 48)

Every property posited by a theory that is not a detection property is an auxiliary property.

According to semirealists, a theory's claims about detection properties are true[5] and these properties are most likely real. We can form different degrees of belief about these claims. The highest degree of belief goes to the properties that we can *manipulate* and a lower degree of belief goes to those that we can simply *detect* but not manipulate. No truth claim can be made regarding theories' claims about auxiliary properties. Therefore, the boundary between claims qualified to be taken as true and claims that are not (yet) qualified as true is the boundary between claims about detection properties and claims about auxiliary properties. As science progresses, this border shifts and some auxiliary properties become detection

[5] Most realists hold that such claims are *approximately* true. Because this qualification is not consequential for our current discussion, for brevity, I use "true" rather than "approximately true."

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properties. This increases the true content of our theories and gets us closer to the aim of finding true theories.

To show the relationship between a theory's truth and its theoretical virtues, I focus on the process through which we realize that an auxiliary property has become a detection property, namely, our ability to detect and manipulate the property. I do this through studying a case of great mastery in the manipulation of properties of an unobservable entity, that is, electron microscopy. Imagine that we have a crude theory of electrons such that all (or nearly all) properties of the electron in this theory are auxiliary properties. According to semirealism, once these auxiliary properties become detection properties, we can say that the theory's claims about the electron are true. This can be done by building a Scanning Electron Microscope (SEM), which demonstrates an impressive level of mastery in detecting and manipulating properties of electrons. How should our crude theory of electrons develop so we can use it to build an SEM?

To answer this question, first, let's see how an SEM works. An SEM generates images by scanning a sample with a high-energy electron beam, produced by an electron gun in a vacuum tube. The electrons pass through electromagnetic lenses, which focus the beam before it interacts with the specimen. This interaction produces various signals, each revealing different specimen features:

- Secondary electrons: Ejected from the sample's surface atoms, they provide high-resolution images of texture.
- Backscattered electrons: Reflected from deeper layers of the sample, their intensity depends on atomic number, aiding in compositional analysis.
- Photons of characteristic X-rays: Emitted from deeper layers of the specimen, they enable elemental analysis.
- Visible light: Produced by excited atoms of the specimen, it can generate color images in luminescent materials.

These signals collectively provide detailed structural and compositional information about the specimen. To collect each of these signals, different detectors should be used. After collecting the signals, through proper mediators they are sent to computers to produce the image and elemental analysis of the specimen.

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How should a crude theory of electrons develop so it can be used for building an SEM? What characteristics should such a theory achieve? First, as Chakravartty points out, we generally describe the processes that connect detection properties to our instruments "in terms of mathematical equations that are or can be interpreted as describing the relations of properties" (2007, 48). To deem a property real, the equations that describe it should be consistent with one another. That is, the theory should be *internally consistent*. Second, the theory should display impressive *empirical fit* and *accuracy*. The area of the specimen that an SEM scans is on the nanometer scale and thus we should be able to make very precise calculations about where the beam of electrons lands. Third, the theory should attain a high degree of *explanatory power* and a broad *scope* to cover all the relevant causal properties of the electron and the mechanisms of its interactions with the specimen, detectors, and electromagnetic lenses. In fact, generating a narrow, high-intensity electron beam with precise focusing, the role of electromagnetic lenses in shaping and controlling the electron beam, systematic scanning of the electron beam across the specimen's surface, detecting variations in electron interactions with different regions of the specimen, and so forth are some of the major theoretical aspects of SEM mentioned in von Ardenne's "The Electron Scanning Microscope: Theoretical Foundations" (1938). Fourth, the theory should have *predictive power*. If it could not foresee the production of secondary electrons, backscattered electrons, X-rays, or visible light, and what aspects of specimen they reveal, we would likely not think of the possibility of different aspects of electron microscopy—in his discussion of signal detection, von Ardenne anticipates that different signals could be used to reveal surface morphology and material composition of the specimen in the future. Fifth, an SEM is a complicated device with many components such as an electron gun, electromagnetic lenses, transmitters, different types of detectors, specimen, computers, and screens. For instance, in his discussion of the resolution limit of SEM, von Ardenne needed to address issues as diverse as electron diffraction effects, aberrations in electromagnetic lenses, the balance between signal strength and damage to the specimen, the interaction of the electron beam with a photographic film, and so on. To address these challenges and to coordinate these components that are built based on different theories, consistency among these theories is needed. Thus, our theory of electrons should be *externally consistent* with other relevant theories. Sixth, as the examples provided from von Ardenne shows—and note that the challenges he addresses pertain to theoretical foundations of the earliest and much simpler

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SEM—the theory of electrons should prove "to have the imaginative resources…to enable anomalies to be overcome and new and powerful extensions to be made. Here it is the *long-term* proven ability of the theory…to generate fruitful additions and modifications" (McMullin 1982, 16). In other words, the theory should be *fruitful*.

In conclusion, for a crude theory of electrons to be elevated to such a level that we can use it for detection and manipulation of the properties that it posits, that is, for the theory to become true according to semirealism, it needs to exemplify an impressive balance of theoretical virtues. So, in the semirealist framework, a theory's truth, detection of the properties that it posits, and its balance of theoretical virtues are closely connected. Now, let's see what their exact relations are.

According to semirealism, we have proper epistemic justification to believe in a theory's truth when the properties posited by the theory are detected. Detection of the properties posited by a theory has two necessary (and jointly sufficient) components: A theoretical component consisting of a *proper* theory of the to-be-detected properties and an experimental component that includes proper instruments to experimentally detect the properties. What makes a *proper* theory for detection? As the case study shows, if the properties that a theory posits are to be detected, the theory should have an impressive balance of theoretical virtues—that is, it should instantiate impressive number and degree of theoretical virtues. So, in the semirealist framework, the relations among a theory's truth, detection of the properties that it posits, and its theoretical virtues are as follows:

a. Detection of a property posited by a theory is the epistemic justification for truth of the theory's claims about the property (because detection is the necessary and sufficient condition for believing that a theory's claims about the property are true).
b. An impressive balance of theoretical virtues by a theory is a necessary (though not sufficient) condition for detection of the properties that are posited by the theory.

To put it more briefly, *detection is the epistemic justification for truth*; *an impressive balance of theoretical virtues is a necessary condition for detection*.

Now we can show that within the semirealist framework, if one commits to Truth-EAST, one should also accept TV-EAST. Let's suppose that the epistemic aim of science is finding true theories. Because detection is the epistemic justification for a theory's truth, we can say that the epistemic aim of science is finding theories that posit detection properties.

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Detection has two necessary (and jointly sufficient) components. The *theoretical* component of detection is finding a theory of the to-be-detected properties that has an impressive balance of theoretical virtues. The *experimental* component of detection is to conduct experiments to detect the properties posited by the theory. Therefore, corresponding to the two necessary components of detection, the epistemic aim of science is twofold. The epistemic aim of scientific theorizing (or EAST) is finding theories with an impressive balance of theoretical virtues and the epistemic aim of scientific experimentation is to experimentally detect the properties posited by scientific theories. Therefore, semirealists should be committed to TV-EAST.

### 4.2. Theoretical virtues and truth beyond semirealism

So far, I have argued that if a semirealist adopts Truth-EAST, she should also accept TV-EAST. But can TV-EAST be incorporated into realist frameworks other than semirealism? Given the diversity of scientific realism, a full discussion of this question goes beyond the scope of this article. Here, however, I offer two arguments to motivate a positive response to this question. These arguments are structured around the central role of theoretical virtues in responses to two major arguments against scientific realism.

First, consider the pessimistic meta-induction argument (PMA). Proponents of the no-miracle argument for scientific realism hold that it would be a miracle for our best scientific theories to be so successful if they were not true. In response, Laudan (1981a) provides a list of past successful theories that eventually turned out to be false and uses it as a base for the inductive claim that we have good reason to think that our current successful theories will also turn out to be false. One major realist response to this argument is to weaken its inductive base by offering more demanding criteria for *success* and limiting the realist claim of truth to *mature* theories (McMullin 1984a; Psillos 1999, ch. 5). These amount to claiming that only *genuinely successful mature* scientific theories are true. These realists claim that since most of the theories that are used to form PMA are neither genuinely successful (*per* their more demanding criteria) nor mature, they cannot be used to challenge scientific realism. Crucially, both qualifications used to address PMA, that is, success and maturity, are understood in terms of theoretical virtues. That is, through these qualifications, realists tend to limit their claim of truth only to those theories that have an impressive balance of theoretical virtues.

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For example, according to Psillos, Laudan's notion of success, which only includes empirical fit, accuracy, explanatory power, and broad scope as virtues of a successful theory, is too weak: "The notion of empirical success that realists are happy with is such that it includes the generation of novel predictions which are in principle testable" (1999, 100). Through this notion of empirical success, Psillos (ibid., 100–2) adds two more theoretical virtues to the list of the virtues that a genuinely successful theory should instantiate: predictive power and non–ad hocness. Psillos also follows McMullin's suggestion that the realist claim of truth is limited to *mature* scientific theories that show a long-term record of explanatory success (McMullin 1987) and prove "continuously fertile and capable of increasingly further extension" (McMullin 1984a, 17). Such theories, according to McMullin, should instantiate what he later calls "diachronic virtues" "that manifest themselves only over the course of time, as the career of the theory unfolds" (2008, 504). These include fertility (fruitfulness), consilience (unification), and durability (empirical fit over a long period and facing variety of tests). To sum up, one major realist strategy to address PMA is to limit the realist claim of truth only to those theories that instantiate an impressive balance of theoretical virtues. But then, if the realist aim of science is finding true theories, in scientific theorizing we should aim at finding theories that instantiate the best balance of theoretical virtues.

Second, according to the argument from underdetermination against scientific realism, all scientific theories have empirically equivalent rivals that agree with one another vis-à-vis the observable but differ vis-à-vis the unobservable. As a result, empirical bodies of evidence can support all these theories equally and hence we have no reason to distinguish one theory as true (van Fraassen 1980, ch. 3). One realist response to this argument is that besides empirical data, "other considerations—most prominently, *explanatory* considerations—play an evidential role in scientific inference" (Chakravartty 2017). These explanatory considerations are a subset of theoretical virtues, usually the ones that are not *directly* related to empirical evidence such as internal and external consistency, non–ad hocness, scope, unification, and simplicity (Lycan 1985; Lipton 2004, 122; Chakravartty 2017). According to this view, in addition to empirical theoretical virtues such as empirical fit, predictive power, and accuracy, those virtues that are commonly considered to be nonempirical are also deemed to be truth conducive (Day and Botterill 2008; Schindler 2018, ch. 1; Bird 2022, ch. 7). If these theoretical virtues are truth conducive and have evidential value in theory confirmation, then it makes sense to pursue the best balance of theoretical virtues in general.

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If my arguments are sound, the seemingly strong association between TV-EAST and antirealism is merely a historical, contingent association and realists who hold Truth-EAST should adopt TV-EAST.

## 5. Defending TV-EAST

In this section, I defend TV-EAST on two grounds. First, I show that it can successfully address the challenges raised against using "the aim of science" metaphor in the literature. Second, I discuss the advantages of TV-EAST over Truth-EAST.

### 5.1. Giving content to "the aim of science" metaphor

Talking about the aims of science (simply "aims-talk") has an odd character in the literature. On the one hand, many prominent philosophers of science such as Nagel, Feigl, Hempel, Kuhn, and Laudan engage in aims-talk—for more recent examples, see Kitcher (1993, 92) and Potochnik (2017). On the other hand, it is not very clear how we can make sense of "the aim of science." Science is not an agent with intentions so we cannot talk about its aim in the same sense that we talk about my aim of traveling to Beirut. Moreover, science seems to be too complex and too diverse to have aim(s) in the sense that the aim of chess is to checkmate the opponent. Due to such difficulties, Resnik (1993) and Rowbottom (2014, 2023, sec. 2) have questioned the appropriateness of aims-talk in science. Resnik's criticism is structured around the failure of aims-talk to provide acceptable content for "the phrase "aims of science" [that] must be taken as a metaphor" (1993, 225). He offers different interpretations for this phrase and claims that none is promising. Echoing Resnik's criticism, Rowbottom (2023, 45–46) offers three "important considerations for deciphering the metaphor":

(i). The aims of science involve or relate to the aims of some scientists.
(ii). The aims of science are characteristic of science.
(iii). For any X to be an aim of science, X must be a rational aim.

Recalling that my discussion is not about the aim of science in general but the epistemic aim of scientific theorizing, in the following, I argue that TV-EAST can successfully addresses Resnik's and Rowbottom's challenges.

According to Resnik's first interpretation of "the aims of science," "a scientific aim is an intentionally sought goal shared by scientists" (225). To see if something is an aim of science in this sense is an empirical question, and therefore Resnik demands "show me that

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set of aims and prove to me that most scientists have these aims" (226). Can TV-EAST satisfy this demand? Schindler's (2022) excellent quantitative study of natural and social scientists (and HPS scholars) shows promising results: Theoretical virtues are widely considered desirable characteristics of theories by scientists and this desirability is not simply pragmatic but epistemic. For most participants in the study, even simplicity, an otherwise low-ranked theoretical virtue, is not merely pragmatic and has epistemic value. Admittedly, this study does not offer *direct* empirical evidence that for scientists theoretical virtues are desirable *as constitutive of EAST*. Maybe they are only desirable as means of achieving a different aim (e.g., problem solving or truth). But, first, the study shows that theoretical virtues are of *epistemic* value for scientists and are not mere philosophical impositions that scientists do not care about. Second, as I discussed in the preceding text, we have reasons to think that TV-EAST is an improvement on the problem-solving account and should be accepted by the proponents of Truth-EAST. Therefore, at the very least, Schindler's study can be used to indirectly and partially address Rowbottom's (i).

According to Resnik's second interpretation, "scientific aims are like corporate aims in that they are goals achieved through cooperation and effective administration" (1993, 227). In this sense, we can reasonably claim that a corporation's aim is to maximize its profit even if most of its employees do not care about this aim. The drawback of this interpretation is that it requires a corporate-like hierarchical structure that science lacks. As Resnik puts it "though some aspects of science may be this way, e.g., compilation of data, undergraduate teaching, and experimentation, other aspects, e.g., theory evaluation, clearly are not. Theory evaluation involves the free-for-all debates" (1993, 227–28). But contrary to Resnik's claim, theory evaluations are not free-for-all debates but free-for-all debates *only among scientists with shared standards of criticism* (Longino 1990, 76). Theoretical virtues constitute these shared standards of evaluation in scientific theorizing and "form that component of disciplinary matrix least subject to variation, both from scientific community to scientific community and over time" (Hoyningen-Huene 1993, 148). This claim is not a philosophical imposition on actual scientific practice either. Empirical and historical studies show that scientists invoke theoretical virtues, explicitly and implicitly, in their evaluation of scientific theories (Kuhn 1977; Tulodziecki 2014; van den Berg 2020; Mizrahi 2022; Wolf and Duerr 2023). In this regard, scientific community has a structure close enough to a corporate-like hierarchical structure that makes possible having this type of aim for scientific theorizing.

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Furthermore, sometimes the standards of evaluation should be thought of as aims. Two notable cases are evaluations regarding scientific rationality and scientific progress. Many hold that scientific rationality is an example of instrumental rationality, that is, the rational adoption of means to reach an aim (Popper 1979; Hempel 1979a; Newton-Smith 1981; Laudan 1990; Thagard 2004) and most understand progress in terms of achieving or getting closer to an aim (Bird 2007; Shan 2022). Therefore, what is appealed to for justifying the rationality of a theory choice or showing that a theory development is progressive can be thought of as an aim of scientific theorizing. And theoretical virtues do play such justificatory role. So, TV-EAST can satisfy this interpretation of the aim of science because theoretical virtues are the shared standards for evaluating whether a theory choice or a theory development is rational and/or progressive. This addresses Rowbottom's (iii).

Finally, Resnik (1993, 229) holds that something can be said to be an aim of science if it characterizes or is constitutive of scientific activity. This interpretation is also consistent with TV-EAST. I only focus on scientific *theorizing* and many agree that theoretical virtues are constitutive of this practice. Recall, for instance, that according to Nagel, theoretical virtues are constitutive not only of EAST but also of scientific theorizing in general because they distinguish scientific theories from common sense knowledge. Here are some other (implicit or explicit) examples of viewing theoretical virtues as constitutive of scientific theorizing (italics are mine): "[For Kuhn,] such features as learning from experience, insistence on consistency, adherence to the desiderata for theory choice, and, in consequence, rationality, are *necessary characteristics* of science" (Hempel 1983a, 571); theoretical virtues "*constitute* a piece of inquiry as science" (McMullin 1984b, 137), they are "the *good-making features* of theories" (Newton-Smith 1981, 226), "*constitutive of* the knowledge and truth-seeking goals of the enterprise of science" (Rooney 1992, 14), "*constitutive values* of science" (Longino 1990, 4), "*constitutive of* science in the sense that we cannot conceive of a functioning science without them" (Laudan 2004, 19), and "*constitutive of* what we understand by scientific knowledge" (Carrier 2009, 203). This addresses Rowbottom's (ii).

### 5.2. Advantages of TV-EAST over Truth-EAST

The first advantage of TV-EAST over Truth-EAST is that it is a *common core* upon which many realists and nonrealists can agree. As we have seen before, many nonrealists (including Hempel, Kuhn, and Laudan) thought of TV-EAST as a competitor of or an alternative to

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Truth-EAST. But I argued that realists should commit to TV-EAST. This means that many realists and nonrealists[6] can agree on TV-EAST. I consider this to be an advantage of TV-EAST, not because it solves a dispute between realists and antirealists about EAST, but, to begin with, because it shows that there should not have been such a dispute. For, assuming that scientific theorizing is an *epistemic* practice and hence its *epistemic* aim is (at least partially) constitutive of the practice, if realism and antirealism are two opposing views about EAST, then the realist's and the antirealist's judgments about different cases of scientific theorizing should diverge. For instance, they should make opposing judgments about whether such and such cases of theory choice or theory development are rational or progressive—recall that rationality and progress are commonly understood with respect to aims. If they end up making similar judgments about virtually all cases of theory choice and theory development, we have reason to think that their disagreement is not really about EAST. But realists and antirealists rarely (if at all) disagree about whether specific scientific theory choices or theory developments are rational or progressive. This suggests that the realism versus antirealism debate is not a disagreement about what constitutes scientific theorizing and its epistemic aim. So, we need an account of EAST that is neutral with respect to realism versus antirealism debate. Unlike Truth-EAST, TV-EAST satisfies this requirement (a point that was also highlighted by Feigl).

Note that I am not claiming that adopting TV-EAST resolves the realism versus antirealism debate. Rather, it puts it in its right place: The debate between *scientific* realism and *scientific* antirealist is not about scientific theorizing and its epistemic aim. It is an *extra*-scientific debate altogether. It is not a debate over whether EAST is finding theories with the best balance of theoretical virtues, but a debate over how (or whether) a theory's impressive success in achieving this aim requires a metaphysical explanation. The "realist move," so to speak, is to offer such a metaphysical explanation in terms of the truth of successful theories. Crucially, however, this "realist move" is not dictated by scientific theorizing (and hence it is *extra*-scientific). Nonrealists and antirealists do not dispute that our best scientific theories succeed in instantiating an impressive balance of theoretical virtues. They resist the realist move because they hold that this success does not require a metaphysical explanation (Fine

[6] Some recent antirealists whose works suggests that they are either committed to TV-EAST or at least find it acceptable are, respectively, Rowbottom (2019, 184–87) and Stanford (2006, chs. 1–2).

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1984), truth does not explain it (Laudan 1981a), or realist explanations are no better than their constructivist foes (Turner 2007).

Second, TV-EAST takes something that is internal to and constitutive of scientific theorizing as its aim. This is one important reason why TV-EAST could give proper content to "the aim of science" metaphor and address the challenges raised by Resnik and Rowbottom. As I showed in section 4, we have evidence to think that *scientists* find theoretical virtues desirable, *scientists* use theoretical virtues as shared standards of evaluation, and *scientists* invoke theoretical virtues in their assessments of scientific rationality and progress. To say the least, it is not clear that truth can satisfy these requirements. In fact, it clearly does not do so if scientists adopt an instrumentalist account of scientific theories. Empirical studies show that some scientists are antirealists and many scientists, although generally realists, are sometimes instrumentalists about the theories they rely on in their research (Beebe and Dellsén 2020; Henne et al. 2024). In such cases, theoretical virtues can still function as constituents of EAST while truth cannot.

Finally, it is obvious that truth *simpliciter* is not a proper candidate for the aim of science. Imagine a group of geologists who carefully count, measure, and classify billions of grains of sand found in a small area on a beach such that we can be sure they form a huge pile of truths about those grains of sand. If truth is the aim of science, this should constitute great scientific progress. Yet, we hardly consider this progress and more likely think of it as an irrational waste of time.[7] The reason is that only some truths are *significant* enough to be incorporated into science. Therefore, if one adopts Truth-EAST, one needs to amend it with a *theory of significance* to clarify which truths are scientifically significant (Kitcher 1993, ch. 4). Popper (1979, 191), for example, holds that science aims for the truths that provide ever deeper explanations. Explanation plays an important role in Kitcher's theory of significance too (1993, ch. 4). But if EAST is finding true explanatory theories, then theoretical virtues, especially explanatory virtues, should be included within the aim of science. That is, Truth-EAST properly explicated should incorporate theoretical virtues such as explanatory power, unification (crucial for Kitcher), and non–ad hocness (underlined by Popper). Thus, Truth-EAST cannot be a standalone account of EAST. However, as Kaufmann argues, theoretical virtues are *determinants of significance* in science. Carrier (2013, 2550–51) has developed

[7] I borrow this example from Bird (2007, 84).

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this idea further, arguing that theoretical virtues "express requirements of significance […that] are influential on the choice of problems and the pursuit of theories in epistemic research" and thereby are "the essential yardstick of epistemic significance" in science. Thus, unlike Truth-EAST, TV-EAST contains within itself a theory of significance and, therefore, is a standalone account of EAST.

## 6. Conclusion

My main objective in this article was to revive and defend TV-EAST, according to which science aims at producing theories with the highest possible number and degree of theoretical virtues. After showing the logical empiricist origins of this account, I argued that Kuhn and Laudan, the two major advocates of the problem-solving account of the aim of science, embraced TV-EAST in their later works. Due to its history, TV-EAST is strongly associated with antirealism. I dissociated TV-EAST from antirealism, arguing that if one adopts Truth-EAST (that science aims at creating true theories), one must commit to TV-EAST as well. Finally, I defended TV-EAST, arguing that it successfully addresses the challenges raised against using "the aim of science" metaphor and it has significant advantages over Truth-EAST.

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