Realism and the Infinitely Faceted World: Intimations from the 1950s

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Reception date / Fecha de recepción: 27-05-2009
Acceptation date / Fecha de aceptación: 22-06-2009

Abstract

Breaking away from logical-empiricism, in the early 1950s Stephen Toulmin presented empirical theories as maps, thereby opening a fertile line of reflection about background interests and their impact on abstraction in scientific theorizing. A few years later, pointing to the "qualitative infinity of nature," David Bohm denounced what he regarded as counterproductive constraints on the scientific imagination. In realist circles, these two strands of suggestions would be variously supplemented over the following decades with further recognitions of the epistemic merits of partial approximate descriptions and the role of background knowledge and interests in scientific theorizing.

Key Words: David Bohm, Stephen Toulmin, David Bohm logical-empiricism, infinity, realism.

Resumen. *Realismo y el mundo de infinitas caras: Presentimientos de los años 50.*

Rompiendo con el empirismo lógico, en la década de 1950 Stephen Toulmin presenta como mapas las teorías empíricas, abriendo así una línea fértil de reflexión sobre los intereses que motivan cada teoría y el impacto de dichos intereses en la abstracción en la teorización teórico/científica. Unos años más tarde David Bohm, señalando el "infinito cualitativo de la naturaleza", denunció lo que él consideraba restricciones contraproducentes en la imaginación científica. En los círculos realistas, estas dos visiones serán complementadas de diversas maneras durante las siguientes décadas con reconocimientos de los méritos epistémicos de las descripciones aproximadas parciales y el papel de los intereses y conocimientos previos en la teorización científica.

Palabras clave: David Bohm, Stephen Toulmin, David Bohm-empirismo lógico, infinito, realismo científico.

Introduction

Today's scientific realists are generally comfortable with the notions that theories comprise idealization and coarse-graining, and that not even the best theories describe their objects either fully or entirely without error[1]. On the affirmative side, realists are as committed as ever to the claims that past successful theories have contributed explanations that remain largely true (even though the full theories turned out to be seriously wrong), and that on the whole the history of mature science give us good reason for expecting that at least significant parts of the best current theoretical accounts are approximately correct[2]. Also gaining adherents among realists is a view of the world as a variegated realm of quasi-autonomous "causal domains" or "levels," each with characteristic entities and processes. And, methodologically, there is growing acceptance that many aspects of the world are best approached through a plurality of perspectives, as exemplified by such pairs as Mendelian and molecular genetics, cultural psychology and bio-psychology, and so forth[3].

Interestingly, these realist moves have precursors in works from the 1950s, notably by Stephen Toulmin on theorizing and map-making, and by David Bohm on the limited applicability of standard theories and what he termed the "qualitative infinity of nature" (QIN). In this paper I want to call attention to some of the ideas in those works, both because of their enduring interest and because of their bearing on the topic of "the infinite" in science studies. One set of insights, stressed by Toulmin in *The Philosophy of Science* (1953) and of interest to constructivists and realists alike, focuses on scientific abstraction and its connection with the presence in theorizing of pragmatic orientations selected from an effectively infinite pool of possibilities. Another set of insights, stressed by Bohm in *Causality and Chance in Modern Physics* (1957) and of interest to methodology and realist ontology, focuses on the inexhaustible number of qualitative levels found in the world and the implausibility of fully describing nature by means of any finite set of universal laws and definitions. Each in their way, Toulmin and Bohm argue for down-to-earth epistemological moderation.

Perspectives to the World

Stephen Toulmin's *The Philosophy of Science* was one of the earliest "post-positivist" books on how scientists "understand" and do their theorizing. According to Toulmin, we deal with the world but our knowledge of it is mediated through concepts. Moving away from the view of theories as inductive generalizations, he advances a "cartographic" view in which

1 Consider, for example, the cases of Philip Kitcher (1993), Jarrett Leplin (1997), and Stathis Psillos (1999).

2 A representative argument of this sort is found, for instance, in Bain & Norton (2004).

3 See, in particular, and Kitcher (2001).

the main goal of theorizing is to locate and orient ourselves in the world. To Toulmin, the main issue about laws and theories is not whether they are strictly speaking "true" but whether and to what extent they "hold." Theories are generally false as universal posits, he observes, but they fare better over judiciously restricted domains.

Appropriate restrictions to impose on a theory vary from case to case and are normally discovered in a gradual fashion, as practice with the theory unveils its limitations and a search for a better approach gathers thrust. Thus, in the case of ray optics (according to which light propagates in straight lines), when diffraction phenomena made trouble and it became unrealistic to expect ray optics to adequately address the problems at hand, the credible scope of analyses in terms of straight lines was restricted rather than reduced to nothing. Toulmin thinks similar reactions are widely held in science, and that we should take theories as restricted generalizations. In his view, the main goals and achievements of theoreticians revolve around seeking the conceptual form and scope of regularities which are found to happen, "not universally, but at most on the whole" (1953: 43). Another suggestion Toulmin makes is that scientific theories enact ongoing interests. Theories, he notes, focus on particular aspects of the world, selected on the basis of background knowledge and specific "interests." They advance "perspectives" on the empirical world. These ideas connect with the suggestion that, in some important ways, theories are like maps.

Toulmin uses analogies from maps to clarify how theories represent their intended domains, noting that, like maps, trustworthy theories have limited scope (explains only a limited range of phenomena), even if this generally takes time to unveil; theories also have a finite level of intended precision; and they embody a variety of tacit qualifications. This way of looking at scientific theorizing has methodological and pragmatic import. Like good maps, "good theories" both increase our understanding and guide our search for further knowledge, as well as our actions over the domain at hand.

The goodness of a theory can be appraised by subjecting it to empirical tests and also by checking its internal consistency and coherence with background knowledge. Typically, discovery of limitations in a theory couples with a search for successors expected to be compatible with the best established parts of the theory (especially at levels closer to observation). This is achieved, for example, by recovering those parts as limiting cases of the successor theories, again as with maps.

The map analogy has proved fertile in philosophy of science. To contemporary realists, maps *exemplify* how strong senses of truth and objectivity can be compatible with significant levels of theory dependence, incompleteness, and social construction and convention[4]. Good cartographic maps give "truthful-enough" representations of relevant aspects of the world, even though they irreducibly embody conventions (about coastal lines, rivers, cities,

4 Giere (1997, 2006), Kitcher (2001), Cordero (2008).

and so forth), cartographic projections (cylindrical, Mercator, etc.), particular goals (a map may focus on physical aspects, as opposed to political, zoological, or other kind of aspects), and socio-cultural contingencies (specific symbols employed, geographical orientation and so forth).

Sensible map-makers never seek to represent any object "completely;" nor could they do so if they wished. In a crucial sense maps are always "partial"[5]. They are also abstract, every map corresponding to some particular perspective of representational interests, out of an infinite pool of possibilities. What a given map specifically seeks to describe, what it includes and leaves out, its scale and level of accuracy, are primarily determined by the map's intended use, always in the context of relevant background knowledge. In the case of maps focused on the Earth, the number of possible maps is at least as considerable as the number of aspects of possible interest to us in it, which is effectively infinite.

No matter what a map tries to portray, it will be *good* only to the extent that the relevant information it provides is accurate within acceptable standards (explicitly or tacitly specified). Despite its being variously limited, a good map tells pertinent truths about its intended domain. One limitation concerns the selectivity of aspects regarding the domain of relevant interests. Another has to do with the intended level of accurate discrimination (1m, 100m, 1Km, etc.), which can never be "perfect" in actual maps. Yet another limitation concerns the range of correct representation (for example, to just the coastal line of a given territory, to 100 Km into the land, etc., depending on the map's intended use). Another is the state of relevant knowledge at the time. In addition, of course, appropriate reading of a map requires knowledge of all the conventions that were employed in its construction. While these restrictions function as limitations, arguably *it is precisely through their judicious implementation that maps manage to achieve their descriptive goals*. (How else but by specifying some coarse-grained range of reliable partial depiction could any kind of "appropriately isomorphic representations" begin to be achieved in cartography?).

Then there is "truth accumulation". On the whole, modern cartographic lineages display *descriptive progress*, especially in terms of accuracy and range of correct representation. But of course, talk of "progress" presupposes the applicability of such value-notions as *good* and *bad*, *better* and *worse*, which are notoriously troublesome when considered in the abstract. Applied to maps, however, rankings are substantially helped by the existence of a "straightforward" standard, namely, conformity to the aspects of the territory in question that are relevant, as determined by the specific uses intended for the map. Importantly, the ongoing concept of correct mapping does not burden the notions of truth and progress with extravagant philosophical baggage.

And so, cartography invites comparison of theory-making to map-making in certain specific respects, particularly the following four:

5 Giere (1997).

(1) In science, theory development aims to improve the description and overview (understanding) of specific aspects of the world found to be significant, as determined by current interests and knowledge. Typically, the study of any empirical domain allows in principle for a multitude of perspectives, infinite in principle—different sets of interests generally giving salience to different aspects of the world. Some perspectives may lead to more epistemic success than others.

(2) What a theory or model seeks to represent depends upon the theory's specific goals, the scales and ranges targeted, the resources available to the scientists articulating it, and so forth.

(3) A given theoretical representation will be correct only to the extent that the descriptions it supplies of the intended domain are correct in "the relevant way."

(4) How to best describe and understand a given part or aspect of the world hinges greatly on the current *state of knowledge*. Present knowledge may sometimes encourage approaching the items of a given domain reductionistically—as being "secondary" relative to the fundamental entities and processes of a larger field. Alternatively, present knowledge may encourage looking at certain items as non-reducible to those of any other scientific field. Then again, it may invite a multi-level approach, as in much of contemporary natural science[6].

Maps are thus a fertile source of inspiration for realists. But *negative analogies* need to be kept in mind as well. In scientific theorizing, matters are not nearly as straightforward as in the case of geographical maps.

(1) Assessing scientific representations generally requires more than just "logic and observation." Concluding that a given theoretical narrative is "presently beyond reasonable doubt" requires prior acceptance of important realist theses, particularly about the epistemic achievements of abduction, and about the scientific discipline at hand having yielded stable enough descriptions of "the unobservable"—as stable and credible as the best empirical claims at ordinary levels.

(2) Far more so than in map-making, much of scientific theorizing is propelled by a tendency to unify previously independent representations. The kind of fruitful unification and integration projects often found in sciences like physics and biology are rare in cartography.

While Toulmin's book stresses the pragmatic character of scientific representation and the restricted scope of the applicability and epistemic import of theories, another book published four years later emphasizes not only the restricted scope of truthful scientific

6 Cordero (2008).

representations, but also the qualitative wealth and multiplicity of effective ontic levels in nature, and the import of relational properties.

Natural Levels and Contexts

In *Causality and Chance in Modern Physics*, published in 1957, David Bohm articulated an early version of his conception of nature as a complex system. In nature, says Bohm, things and processes arise, develop and dissolve within environmental contexts; different contexts giving rise to different manifestations of an intricate relational causal order whose totality, in his view, defies full exploration (let alone representation). Two related ideas from this early work are particularly relevant to this paper's focus on the infinite and the realist project in science studies. One is something Bohm termed the "qualitative infinity of nature" (QIN); the other is his conception of the scope and limits of scientific descriptions.

Bohm's thinking on QIN revolves around three main themes: (A) the kinds of things found in nature, (B) ontic levels of interaction and endurance, and (C) contextuality.

(A) Science, Bohm notes, keeps unveiling new *kinds of things* in nature, a seemingly unlimited variety of qualities, processes, and relationships; and neither the discovery of new things nor the development of concepts appropriate for them have any signs of coming to an end. Repeatedly, he reminds his readers, entities once presumed immutable have turned out to be subject to fundamental transformations. For instance, until the end of the 19^{th} century, studies of the structure of matter routinely assumed that the fundamental qualities and properties defining the modes of being of matter and its components were limited in number. But then further studies disclosed details of an active substructure in atoms. Electrons were found around a nucleus made of protons and neutrons, and shortly after these subatomic particles were found to comprise numerous kinds of quantum mechanical fluctuations. More discoveries followed, including some previously unimagined processes that lead to the formation of such unstable particles as hyperons and mesons, which can be "created," "annihilated" and transformed into each other. Additional substructures, involving a plethora of properties and qualities, have been unveiled since, along with still deeper-lying kinds of entities and processes. To Bohm, the microphysical realm is inexhaustible in the qualities and properties it can have or develop, and in his view so too is everything else in nature.

(B) More than just variety is apparent in nature, however, according to Bohm: the various kinds of things that have been discovered are organized into a complex array of "levels," seemingly infinite in number. Bohm thinks of levels in terms of the characteristic entities and processes each displays. They are, he says, naturally constituted by sets of entities ("things," in his terminology) effectively closed under certain kinds of processes, within specifiable restrictions. For example, most atoms are stable in ordinary human environments, but under bombardment with high-energy particles the nuclei of various chemical elements atoms can be excited and transformed into new kinds of nuclei, with radical changes in their physical and chemical properties. Neutrons can be transformed into protons, and indeed many particles are unstable, so that their mode of existence implies their capacity for turning into different kinds of particles. Microphysics, Bohm concludes, suggests the existence of level within level of smaller and smaller kinds of entities, each of which helps to constitute the substructure of entities above it in size.

Now, for things to give rise to levels they must have some degree of *stability* in their modes of being. If relatively and approximately autonomous things did not exist, then whatever laws there are would not be discernible by us, as they could not in principle be tested by altering conditions with the help of experiments, Bohm reasons. Thus far science has found no shortage of autonomous enough entities. Their relative autonomy has many origins, he points out, most commonly electrical screening, the falling of the propagation of interactions with distance between the things involved, the decay of certain influences with the passage of time. Other factors have to do with individual constituents of an object being too small (such as atoms relative to ordinary objects) to have an appreciable effect on the object as a whole, while collectively there is a considerable independence of motions of the constituents (thus leading to the cancellation of chance fluctuations). Yet another factor is the existence of thresholds, such that influences which are too weak to surpass these thresholds fail to produce significant effects. Bohm is confident that many other such sources of autonomy will be discovered in the future. On the other hand, although the levels that result from all this have significant autonomy from each other, they also depend on one another for their constitution, says Bohm, each level entering into the substructure of the higher levels. Bohm is attentive to ways in which the characteristics of each level depend partly on conditions in the background provided by other levels (higher and lower) and partly in the level at hand.

(C) Then there is what we now call "contextuality." Bohm is impressed by how the basic qualities that "define" the mode of being of just about all entities found in nature undergo fundamental transformations when conditions alter sufficiently. For example, as said, atoms behave like indivisible particles under a wide range on conditions; however, under sustained electric discharges atoms can be exited and ionized, and when this happens they acquire new physical and chemical properties. For any given structure found in nature, Bohm urges, it is always possible that further studies will disclose further organization in its entities and regularities. Even when a system behaves as if it were completely independent from everything else, it is still subjected to influence from the general background, he insists. In his view, this importance of the background is explicitly recognized by the various physical fields that were in place in the conceptual structure of mid-20th century physics. These fields, whose mode of existence requires that they be defined over broad regions of space, enter into the definition of the basic characteristics of all the fundamental particles, Bohm stresses. When excited the fields give rise to qualitative transformations in the particles; in turn, the particles have an important influence on the character of the fields.

So, according to Bohm, the basic qualities and properties of each kind of entity depend not only on their substructures but *also* on what is happening in their general background. He has in mind two main claims here. One is that lower levels affect higher levels and higher levels affect lower levels in *reciprocal relationships*. The second claim is that future physics will probably show the inadequacy of the time-honored approach of just going through level after level of smaller and smaller particles. Instead, Bohm expects, the background will be recognized as entering fundamentally even into the definition of the conditions for the existence of the new kinds of basic entities physics will unveil.

Bohm's rationale for the latter claim is not terribly clear. To him, completely separate, autonomous entities are idealized abstractions provisionally lifted out of an infinite and unlimited totality. Such abstractions, he urges, have applicability, but only within certain domains and then under certain conditions. Even though a thing may be seen as independent, it is still subjected to influence from the background. Considerations such as these move Bohm's reflections toward conclusions akin to Toulmin's on the scope and limits of scientific theories. What we find in nature, Bohm says, is mountains, dogs, trees, atoms, protons and so forth, all of them dynamical structures that behave as invariant, "thing-like" *only within limited contexts*. In all cases, he urges, a sufficiently dramatic change of context would prompt any given "thing" to give way to new structures and processes. There is no *ultimate* structure to matter, or to anything, he advises.

What knowledge, then, does physics yield? Given the complex relation that everything bears to its background, any proposed finite set of laws should be received with the greatest circumspection, Bohm thinks. As he puts it:

> No matter how far one goes in the expression of the laws of nature, the results will always depend in an unavoidable way on essentially independent contingencies which exist outside the context under investigation, and which are therefore undergoing chance fluctuations relative to the motions inside the context in question. For this reason, the causal laws applying inside any specified context will evidently not be adequate for the perfect prediction even of what goes on inside this context alone.
> Secondly, however, the essential independence of different contexts implies that the processes taking place within a given context cannot provide a complete and perfect reflection of what goes on in the infinite totality of possible contexts." (Bohm, 1957:158-59)

There is a "fundamental level," Bohm agrees; it is just not found in the parts but in the whole, in the full richness of the patterns of natural law.

> All the laws of the various levels and all the different general categories of law, such as qualitative and quantitative, determinate and statistical, etc., represent different but necessarily interrelated sides of the same process. Each side gives an approximate and partial view of reality that helps correct errors coming from the sole use of the others, and each treats adequately an aspect of the process that is not so well treated or perhaps even missed altogether by others." (Bohm, 1957: 66–67)

Bohm seems to have the following picture in mind:

(1) Qualities, properties of matter, and categories of laws expressed in terms of some finite set of qualities and laws are generally applicable only within limited contexts (in terms of ranges of conditions and degrees of approximation).

(2) We should expect the existence of an unlimited variety of additional properties, qualities, entities, systems, levels, and so forth, to which new *kinds* of laws of nature apply.

(3) There is no reason to suppose that new qualities and laws will *always* lead to mere correction refinements that converge in some simple and uniform way. This may occur in some contexts and within some definite range of conditions, but in different contexts and under changed conditions the qualities, properties and laws may be quite novel and lead to dramatic effects relative to what previous theorizing would have led to expect. For example, for mobiles with relative speeds negligible to the speed of light in a given frame, the laws of relativity lead to small corrections of the laws of Newtonian mechanics. But they also lead to such qualitatively new results as the "rest energy" of matter. Further laws yet to discover may be vastly more bizarre.

We thus get Bohm's position on theories: good theories give us knowledge but they don't give us everything there is to know about their intended domains, let alone the world. Finite sets of simple laws can provide good descriptions and predictions when we constrain their context enough, says Bohm, but we should expect unrestricted theories to be false.

The above views are rich in methodological implications. According to Bohm, a historically educated conception of the laws of nature must reflect these realizations and make explicit recognition of their contingency. Much is to be gained, he thinks, if we adopt the notion of the qualitative infinity of nature[7], not least a concept of the nature of things which agrees with what Bohm regards the most basic and essential characteristic of the scientific method, namely, the requirement of continual probing, criticizing and testing of every feature of every theory, no matter how fundamental that theory may seem to be. If there is no end to the qualities of nature, there can be no end to our need to probe and test all features of all of its laws. In addition, says Bohm, QIN frees scientific research from the

7 Bohm (1957):15.

irrelevant restrictions that result from supposing that a particular set of general properties, qualities, and laws *must* be the correct ones to use in all possible contexts and conditions and to all possible degrees of approximation. In Bohm's view, all that we lose by shifting to QIN is the illusion that we possess good grounds for believing that, in principle, we can or eventually will be able to predict everything that exists in the universe in every context and under all possible conditions.

Some applications

To both Bohm and Toulmin, successful theories contribute correct assertions about nature, so long as the theories are suitably restricted to specific contexts and degrees of approximation. Toulmin's analogy with maps emphasizes both the intentional underpinnings of scientific theorizing. Bohm's views emphasize how ultimately false theories can nevertheless provide correct partial descriptions at relevant "local," restricted levels. So, do theories achieve "truth by restriction" in actual science, and if so how? This matter is best explored with the help of a few examples.

In 1897 J. J. Thomson proposed that cathode rays are made of charged. Thomson's thinking proceeded entirely along the lines of Newtonian mechanics and classical electromagnetism. By deflecting cathode rays with the help of controllable magnetic fields and comparing the results with those for deflections with hydrogen ions, Thomson realized that in cathode ray corpuscles the mass to charge ratio had to be much lower than for hydrogen ions. He proceeded to determine the precise value for his hypothetical corpuscles, which he associated with the "unit charge" that George J. Stoney had named "electron" in 1894[8].

Thinking of cathode rays as swarms of Newtonian corpuscles, helped by magnets and electrostatic fields Thomson produced assorted deflections in his laboratory. Using only classical physics to analyze the experimental outcomes, he derived the following estimate for the mass to charge ratio[9]:

$$(m/q)_e = [0.85 \pm 0.34] \times 10^{-7} \text{gr/esu}$$

The above value is close to the one yielded by *current theory*, even though the theories employed for its determination have been discarded for about a century now. But here comes the point raised by Toulmin and Bohm. To a significant extent, this claim about the electron is true because of the coarse-graining it incorporates. Thomson determined the mass to charge ratio within theoretical-experimental margins of 0.34×10^{-7}gr/emu.

8 This unit had been introduced in the 1840s to explain the chemical properties of atoms.

9 Bain & Norton (2004).

Representing this coarse-graining by "$\delta_{m/q}$," we get a claim of the following form about the electron:

For all electrons, {$Á_{m/q}$ (e) = yielded value $\pm \delta_{m/q}$}

In due course, Thomson's derivation from classical theory turned out not to hold universally, however. The dependency of mass on relative speed restricts the applicability of Thomson's result to just electrons moving at low speeds relative to the speed of light, say ones with ratios v/c ~ 1/10:

For electrons with v/c values within the range $\Delta_{v/c}$ = [0, 0.1],
{$Á_{m/q}$ (e) = yielded value $\pm \delta_{m/q}$}.

Let us represent the form of the claim, including the noted restriction on its range of application as:

[$Á_{m/q}$ (e); $\delta_{m/q}$, $\Delta_{v/c}$]

Now, even with these restrictions, the expectation that the above claim should hold in subsequent theories seems extraordinary. No less so is this further historical fact: the values for the mass to charge ratio yielded by all the theories of the electron with empirical laurels have yielded ratios *increasingly closer to the current value*. Representing proximity to current value by a parameter, "$\varepsilon_{m/q}$," the proximity of Thomson's result to the latest determination for the charge/mass ratio is given by:

($\varepsilon_{m/q}$) = | value (Thomson's theory) – current estimate |
= 0.28×10^{-7} gr/esu.

The general form for the stable generalization about the electron's charge to mass ratio may thus be represented as:

[$Á_{m/q}$ (e); $\delta_{m/q}$, $\varepsilon_{m/q}$, $D_{v/c}$]

The realist point here is that classical physics unveiled some important truths about the electron, even if in a coarse-grained fashion, and with important restrictions. Indeed, as Bain & Norton (2004) have noticed, classical physics yielded virtually all the features that got to be successfully predicted up to 1925. Although determined with the help of Newtonian mechanics and classical electromagnetism, the descriptive claims for those features are nonetheless very close to the present estimates. For instance, guided also by the same classical approach Thomson had used, Robert Millikan determined that all electrons carry the same unit of charge of [4.774 $\pm$ 0.001] x 10^{-10} esu, which he identified with the *atomic value of charge in nature*. The current estimate for the electron's charge is [4.80325 $\pm$ 0.00001] x 10^{-10} esu.

From a contemporary perspective, Thomson got the value for $(m/q)_e$ somewhat *wrong*, and Millikan got the value for the electron's charge somewhat *wrong*; but their respective results were by no means completely off the mark. Other properties got similarly imperfect estimates, but again the values obtained were not totally off the mark, and they were gradually improved by subsequent theories applied in conjunction with better experimental techniques. Millikan's pronouncement about charge in physical systems was also wrong about its scope—as it turned out, not all charged particles carry whole numbers of the electron's charge (quarks carry 1/3 that value).

Nevertheless, the relevant claim is that important results from strictly classical treatments of the electron were close to the mark and were improved by subsequent theories. Realists argue that these seemingly modest facts about theory succession would be extremely surprising unless the said claims derived from classical theory are *basically true*, at least once restrictions like the ones outlined above are spelled out. This kind of convergence, realists urge, is not something one finds in sequences of merely imaginative constructs. Admittedly, each subsequent theory of the electron has brought with it changes at the levels of the conceptual framework in which its descriptions are embedded; but, as Bain & Norton and other realists urge, mathematical descriptions of some key aspects unveiled at each stage have remained unchanged ever since.

I would suggest, however, that the succession of theories at hand displays more than accumulation of mathematical description[10]. *Physical descriptions* of key aspects of the electron and other systems, including rather elaborate theoretical narratives unveiled at each of the stages, have remained unchanged enough as well (again, within restrictions specified at subsequent stages). If so, the fuller realist claim to make is that, in many respects, electrons are as classical physics dictates. To be sure, the developments of quantum mechanics from the mid-1920s on have vastly enriched the representation of the electron, yet the resulting new theories have, again, "maintained" numerous results derivable from Newtonian classical physics, albeit usually not as sharp-value properties but as quantum mechanical averages. Furthermore, nomological and spatial relations involving electrons, atoms and the like are recovered as relations on quantum-mechanical averages, typically via Ehrenfest-like theorems.

The highlighted conceptions of scientific theories developed in the 1950s by Toulmin and by Bohm resonate quite well with current efforts on behalf of the project of scientific realism, it seems.

10 Cordero (2007).

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