Optimistic Realism about Scientific Progress

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ABSTRACT: Scientific realists use the "no miracle argument" to show that the empirical and pragmatic success of science is an indicator of the ability of scientific theories to give true or truthlike representations of unobservable reality. While antirealists define scientific progress in terms of empirical success or practical problem-solving, realists characterize progress by using some truth-related criteria. This paper defends the definition of scientific progress as increasing truthlikeness or verisimilitude. Antirealists have tried to rebut realism with the "pessimistic metainduction", but critical realists turn this argument into an optimistic view about progressive science.

KEYWORDS: conceptual pluralism, fallibilism, no miracle argument, pessimistic metainduction, scientific realism, truthlikeness

1. Varieties of Scientific Realism

Scientific realism as a philosophical position has (i) ontological, (ii) semantical, (iii) epistemological, (iv) theoretical, and (v) methodological aspects (see Niiniluoto 1999a; Psillos 1999). It holds that (i) at least part of reality is ontologically independent of human mind and culture. It takes (ii) truth to involve a non-epistemic relation between language and reality. It claims that (iii) knowledge about mind-independent (as well as mind-dependent) reality is possible, and that (iv) the best and deepest part of such knowledge is provided by empirically testable scientific theories. An important aim of science is (v) to find true and informative theories which postulate non-observable entities and laws to explain observable phenomena.

Scientific realism became a tenable stance in the philosophy of science in the 1950s as an alternative to empiricist views which reduced theories to the observational language (Ernst Mach's *positivism*) or restricted scientific knowledge to the level of observational statements by denying that theoretical statements have truth values (Pierre Duhem's *instrumentalism*). C*ritical scientific realism* can be distinguished from naïve or metaphysical forms of realism by two additional theses: (vi) fallibilism and (vii) conceptual pluralism.

According to the principle of *fallibilism*, all factual human knowledge is uncertain or corrigible. This thesis was formulated by Charles S. Peirce in the late 19th century by arguing that science "approaches to the truth" with its "self-corrective method" (*CP* 5.575). John Dewey's pragmatism developed fallibilism with an epistemic concept of truth as warranted assertability (see also Sellars, 1968, and Putnam, 1981), while critical realists have combined fallibilism with the semantical thesis (ii) by adopting Alfred Tarski's model-theoretical explication of the correspondence theory of truth. Thus, against semantical antirealists like Michael Dummett, a scientific realist accepts that there are unknown and even recognition-transcendent truths about the world. The task of science is to apply and improve critical methods for solving cognitive problems about such so far unknown truths. The progress of science as such a theoretical enterprise is tested by its empirical success, since for a realist the best explanation of the empirical success of theories is the assumption that they are true or truthlike (see Section 3).

Some realists are extremely cautious fallibilists who take truth to be a regulative ideal or aim of scientific inquiry. Thus, realism has been defined by the weak condition that theories are *possibly true* (Mäki, 2002). Probabilistic versions of fallibilism take theories to be *probable* (or probably true) on the basis of observable evidence, where epistemic probability measures degrees of belief (certainty and uncertainty). Susan Haack's (2007) "innocent realism" avoids exaggerated claims about the achievements of inquiry: while science is increasingly successful empirically and theoretically, we cannot claim that all scientific theories are true. Stathis Psillos (1999) formulates his epistemic thesis so that "mature and predictively successful scientific theories are well-confirmed and approximately true of the world". In Section 4, we shall return to the question about the epistemic status of successful theories.

Strong forms of fallibilism are ready to assert that typically theories are false, even known to be false, since they contain approximations and idealizations, but still one hypothetical (even false) theory may be "closer to the truth" than another theory. Karl Popper (1963) tried to define this key idea of fallibilism with his notion of *truthlikeness* or *verisimilitude*. By the same token, it is meaningful to state that a sequence of theories "approaches to the truth", even when the final limit is not reached. Since 1974, after the failure of Popper's attempt, a number of alternative and still debated precise definitions of truthlikeness have been given (see Oddie, 1986, 2014;

Niiniluoto, 1987, 2007; Kuipers, 2000; Schurz and Weingartner, 2010). Here the logical or objective notion of truthlikeness tells how close a theory H is to a target C*, which is the complete truth about the world as far as it can expressed in a given conceptual framework L. The degree of truthlikeness Tr(H,C*) of H is maximal if and only if H is equivalent to the complete truth C*.[i]

(1) Tr(H,C*) is maximal if and only if H = C*.

This degree can be high even when H is false. A theory can be said to be *truthlike* if its degree of truthlikeness is sufficiently large – at least more truthlike than the weakest truth or a tautology. Most explications allow that some informative false theories may be truthlike in this sense. The relevant language L can be chosen in a flexible way, so that the alternative targets C* may include singular statements about individual objects, qualitative predicates, quantities, existence claims, generalizations, and laws. In the special case where C* includes only laws, verisimilitude is often called *legisimilitude*.

The epistemic notion of truthlikeness tells how close we can estimate theory H to be to the target C*, given our background knowledge and available evidence E. Niiniluoto's (1987) solution to the epistemic problem assumes that a rational probability measure P is defined for the language L, so that the posterior epistemic probability $P(C_i/E)$ given evidence E is defined for each constituent (complete theory) C_i in L. Then the unknown degree of truthlikeness Tr(H,C*) may be estimated by its *expected* value relative to the constituents C_i and their posterior probabilities given evidence E:

(2) $\mathrm{ver}(H/E) = \sum P(C_i /E)\, \mathrm{Tr}(H,C_i)$

where the sum goes over all constituents of L.[ii] It is important that ver(H/E) may be high even when P(H) = 0 or P(H/E) = 0.

Some realists like Psillos (1999) suggest that formal issues concerning approximate truth and truthlikeness are not needed, if the operative notions are intuitively clear and do not lead to paradoxes, but this does not answer Larry Laudan's (1984) claim that talk of verisimilitude is "so much mumbo jumbo". We shall see in Section 2 that this notion helps the scientific realist to define *scientific progress* as theory-change with increasing truthlikeness (see Niiniluoto 1984, 2014).

Another key idea of critical realism is *conceptual pluralism*. All inquiry is relative to some conceptual framework which is used by the scientists for describing reality. This is what Immanuel Kant argued in his critical philosophy, but Kant thought that we are prisons of our native forms of sensibility and understanding. Critical realists instead argue that such conceptual frameworks can be changed, revised, and enriched. Already William Whewell argued that scientific languages should be chosen so that they enable us to formulate informative true general statements or laws (see Whewell, 1840, p. 509). If a language lacks expressive power, we can always add new terms to its vocabulary. This idea was developed by Peirce in his semiotics or general theory of signs. Such dynamic conceptual change is an important feature of the progress of science.

Conceptual pluralists go further in claiming that the world can be categorized in alternative ways with different conceptual frameworks. This idea is emphasized by Putnam's (1981) *internal realism*, while *metaphysical realism* accepts a "ready-made world". Psillos (1999) formulates his metaphysical thesis by stating that "the world has a definite and mind-independent structure". He further argues that if objects and structures are constituted by conceptual schemes, this leads to "constructivist antirealism" or "perspectival relativism with epistemic truth", where the objective world is either lost or reduced to "a noumenal blob without any resistance to our conceptualizations" (Psillos, 2009). Here he agrees with Putnam's inference that the rejection of metaphysical realism would lead to an epistemic notion of truth (as ideal acceptability). However, against Putnam, critical realists have combined conceptual pluralism with the correspondence theory of truth (see Niiniluoto, 1984, 1999a; Tambolo, 2014). The basic idea is that THE WORLD is mind-independent, but it has a conceptualization W_L for each semantically determinate language L. Here W_L is an L-structure, in the sense of model theory, which represents THE WORLD as far it can be described in L. Thus, the truth of sentences of L in W_L is well-defined by Tarski's semantic theory. Conceptual pluralism now means that we need not accept with Sellars (1968) the existence of an ideally adequate "Peirceish" conceptual framework, i.e. there is no language L such that THE WORLD is an L-structure. Each language L has its own truths, but still truth is objective in the sense that we are free to choose the language L (with its vocabulary and interpretation), but THE WORLD decides the extensions of the L-terms and the truth values of L-sentences. Further, truth is not relative, since the truths about different L-worlds are all determined by the same WORLD and therefore cannot be incompatible with each other (see Niiniluoto, 2014c).[iii]

Also Philip Kitcher has moved from his earlier "monism" (i.e. the world has a unique structure which can be represented in a complete theory) to "modest realism" which combines truth as correspondence with conceptual relativity (see Kitcher, 1993, 2001; Diéguez, 2011). Kitcher states that our conceptual frameworks "draw new boundaries in nature", but defends - against doubts raised by Helen Longino - the compatibility of truths in different languages.

Scientific realists have traditionally assumed, against instrumentalists, that all scientific statements have truth values (Niiniluoto, 1999a). Later developments include versions which restrict truth claims to existential postulates (Hacking's and Cartwright's *entity realism*) or universal and probabilistic laws (Worrall's *structural realism*). We shall indicate below some problems in these half-realist positions: the determination of theoretical ontology involves the laws of the theory, and it is quite typical to modify the laws of a theory in order to find more truthlike ones. Chakravartty's (2009) *semirealism* agrees with entity realism by including objects in its ontology, but restricts structural features to "detectable properties". Also other versions of *selective realism* have been proposed as responses to antirealist arguments, but it is not always clear whether their restrictions of are meant as semantic (the excluded statements lack truth values) or epistemic (the excluded statements lack evidential commitment). Kitcher's (1993) distinction between "idle" (presuppositional) and "working posits", as well as Psillos's (1999) strategy of "divide et impera", can be understood in the latter sense, since they try to express what part of a theory is responsible for its empirical success and thereby gains epistemic support.

Ontological interpretation of selective realism is also advocated by *ontic structural realism*, which asserts that only the structure of the world is real (see da Costa and French, 2002). Such structure is expressed by relations and laws, so that objects and qualities are dispensed (or in some way constituted by structural features). This is a variety of metaphysical realism, as it assumes a unique structure of the world.[iv]

2. Theories of Scientific Progress

Since the 1950s philosophers of science have proposed various accounts of theory change.[v] Reconstructions of actual developments in science include, among others, reduction relations, theory evolution, scientific revolutions, and research programs. These studies are important, since a philosophical theory of scientific progress should be able show that major historical examples of scientific advancement have been progressive. However, accounts of theory change do not necessarily tell about scientific progress, since 'progress' is an axiological or a normative concept which should be distinguished from neutral descriptive terms like 'change' and 'development' (see Niiniluoto, 2015). To say that step from stage A to stage B constitutes *progress* means that B is an improvement of A or better than A relative to some standards or criteria. In particular, the notion of scientific progress should reflect the aims of good science. Fallibilist realists should not claim that *all* actual changes of scientific theories have been progressive. Temporary regress is also a possibility,[vi] even though the self-corrective method of science attempts to guarantee that theory change typically is improvement.

The most traditional model of scientific progress, shared by many rationalists and empiricists, is *accumulation of knowledge*. This view is associated with infallibilist epistemology which assumes that science can establish certified truths so that there is later no need to reject or correct them. Today most philosophers think that this kind of epistemology is outdated, and the cumulative model of progress is refuted by radical changes in the history of science. In the early modern science, Ptolemy's geocentric astronomy was overthrown in the Copernican revolution, and the medieval impetus theories were replaced by the new mechanics of Galileo. For two centuries Newton's mechanics was the most celebrated achievement of science, which was held to be true by most members of the scientific community, but still it was replaced by relativity theory and quantum theory in the early 20th century. Instead of accumulation, these new theories correct the earlier one by including it at best as a counterfactual special case. So according to the "principle of correspondence", a new theory contains the old one approximately (Popper, 1979, p. 202). Something similar happens even in paradigmatic examples of cumulative growth: when Newton's theory unified the empirical laws of Galileo and Kepler, as Whewell (1840) rejoiced in his notion of "consilience of inductions", it explained these laws only approximatively. In radical theory changes, such as the transition from phlogiston theory to oxygen theory, the postulated theoretical entities of the old theory are overthrown and replaced by different kinds of entities.

Critical realists, who wish to claim that science makes *theoretical progress* on the level of theories, have proposed an alternative to the cumulative view: by taking seriously the Peircean idea that science approximates the truth at least in the long run, Popper (1963) characterized scientific progress as *increasing truthlikeness*. His proposal was immediately rejected by Thomas Kuhn, who asked whether it really helps "to imagine that there is some one full, objective, true account of nature" so that "the proper measure of scientific advancement is the extent to which it brings us closer to that ultimate goal" (Kuhn, 1970, p. 171). Kuhn is right that "evolution-from-what-we-know" is easier to assess than "evolution-toward-what-we-wish-to-know" – this is, indeed, one of the virtues of the old cumulative model of progress. How could we define progress by approach to some unknown and perhaps infinitely complex destination? By analogy, sequences of natural numbers may approach the infinite number ω as their ideal limit, but any two finite natural numbers m and n are still infinitely distant from this limit (since $\omega - m = \omega - n = \omega$). But it makes sense to say that m is closer to ω than n if and only if, for some natural number $k \geq m$ and $k \geq n$, m is closer to k than n. Similarly, following the basic idea of conceptual pluralism, theories H and H’ may be compared for their truthlikeness relative to the target C*, where C* is the complete truth in a conceptual framework which includes both H and H’. In this sense, definition of progress by comparative truthlikeness does not presuppose that we are able to measure the distance of theories from some ideal “Peirceish” goal. This is enough to show that the idea of progress as increasing truthlikeness makes sense without any questionable metaphysical assumptions (see Niiniluoto, 1984).[vii]

Given the distinction between objective truthlikeness Tr(H,C*) and its estimate ver(H/E), a similar distinction has to be made concerning the notion of progress: one should distinguish *real progress*, which need not be recognized by us insofar as the target C* is unknown, and *estimated progress*, which is accessible to our judgment on the basis of available evidence. So let us say that

(3) step from theory H to theory H’ *is progressive* iff Tr(H,C*) < Tr(H’,C*)

(4) step from theory H to theory H’ *seems progressive* on evidence E iff ver(H/E) < ver(H’/E).

According to definition (3), objective truthlikeness Tr gives an ahistorical standard for telling how close we really are from the target C*, even when we don’t know it, and likewise a standard of real progress in science. According to definition (4), estimated verisimilitude ver expresses our judgments about progress, sensitive to historically changing situations with variable evidence. In contrast, decrease of objective or estimated truthlikeness is a mark of *regressive* development in science.

Piscopo and Birattari (2010) complain that estimates of verisimilitude by ver(H/E) are not objective, as they depend on evidence E and can be revised with increasing evidence. But, even though a critical realist admits objective concepts of truth and truthlikeness (i.e., Tr), for a fallibilist all claims about the truthlikeness of theories and likewise claims about real scientific progress have to be based on some evidence – and they are equally conjectural as claims about truth. Even when ver(H/E) is high, our claim that H is really truthlike may be mistaken. The strongest sense of objectivity which can be demanded of a fallible measure like ver is that, on some conditions about appropriate and increasing evidence E, the value of ver(H/E) approaches the correct value Tr(H,C*) relative to the true target C* (see Niiniluoto, 2007).

In axiological terms, definition (3) expresses the view that the primary aim of science is informative truth: science is a truth-seeking and falsity-avoiding activity, whose success is measured by the truthlikeness of its best theories. At least when the target C* is expressed in a sufficiently rich conceptual framework, this primary aim guarantees that the best theories also have explanatory and predictive power.[viii] For applied science, the secondary aims could include such virtues as simplicity, manageability, and social relevance.

Examples of general results concerning the notion of scientific progress include the following kinds of theory change:

(5) (a) from ignorance $H \vee \neg H$ to true H

(b) from ignorance $H \vee \neg H$ to sufficiently truthlike H

(c) from a true theory to a logically stronger true theory

(d) from a false theory H to its truth content $H \vee C^*$

(e) from a false theory to a sufficiently informative true theory

(f) from a false theory to another false theory closer to C*.

Here (a) and (b) show how the emergence of a new theory can improve our cognitive state. (b) allows that sometimes a step from a weak truth to an informative falsity may be progressive, but (e) shows that informative truth wins falsities. According to (a) and (c), accumulation of truths is progressive. Oddie's (1986) definition of truthlikeness does not give a plausible account of progress, since it fails to satisfy (c). (d) is Popper's (1963) truth content principle, and (f) is the crucial condition that Popper's own definition failed to satisfy.

Definitions (3) and (4) presuppose that theories are assessed relative to the same target C*. This is motivated by the idea that the compared theories have to be rival answers to the same cognitive problem. If H and H' are expressed in different languages L and L', (3) has to be modified by translating these theories into a common conceptual framework which an extension of L and L'. In the richer framework, one may find continuity between theories H and H' so that it is possible to speak about convergence to the truth. Schurz (2011) shows this with his notion of structural correspondence, which links theoretical expressions responsible for the success of a superseded theory to some theoretical expressions of the superseding theory.

Reference invariance in spite of meaning variance and incommensurability can be defended also on the basis of appropriate theories of *reference*. For the realist, whose account of scientific progress includes sequences of the type (5e), it is important that e.g. rival theories of electrons by Lorentz and Bohr can be construed so that they refer to the same theoretical entity, even though both of them gave in some respects mistaken descriptions of its nature. Similarly, the transition from Rutherford to Bohr's and Sommerfeld's theories of the atom illustrates progress as truth approximation (Hettema and Kuipers, 1995). However, Frost-Arnold (2014) has argued that the realist has to either accept semantic antirealism or reject common semantic views, since on "standards views in philosophy of language" (such as direct reference theory and Fregean descriptive theory) reference failures lead to certain sentences being neither true nor false. For example, on those accounts, `Caloric is weightless` is truth-valueless or meaningless, so that it does not express a proposition at all. But already Russell in 1907 showed how the sentence 'The present king of France is bald' can be understood as involving a mistaken existence claim, so that it is meaningful but false. Kitcher (1993) has argued, by causal and descriptive accounts of reference, that at least some tokens of terms like 'phlogiston' and 'dephlogisticated air' can refer to oxygen, or 'ether' can refer to the electromagnetic field (cf. Psillos, 1999; Ladyman, 2002). While ordinary Fregean theory allows a theoretical term to refer only to those entities which the theory describes truly, so that a false theory cannot refer to anything, one can combine the descriptive theory of reference with a Principle of Charity: a theory refers to those real things which it describes in the most truthlike way (see Niiniluoto, 1999a, pp. 128-132). On this account, it is meaningful to state that rival false theories refer to the same entity and one of them gives a more truthlike description of it.

Idealized theories give important illustrations of progressive shifts in science (see Nowak, 1980). In these examples, the laws are modified to make them more truthlike. Galileo's study of free fall accepted the deliberate idealization that resistance of air is excluded, so that his famous law was known to be false with respect to real motions. Truthlikeness is increased when this idealization is first made explicit and then the equations are corrected by "concretization", i.e. by introducing resistance of air as an additional factor into the law. Such corrections can be calculated by using Newton's mechanics which itself turns out to be – in the light of relativity theory and quantum theory - an idealization in some respects. Similarly, Boyle – Mariotte law $pV = RT$ for ideal gas can be concretized by van der Waals law $(p + a/V^2)(V - b) = RT$, which takes into account intermolecular attractive forces a and the finite size b of gas molecules. This equation, derived in 1873, is a progressive improvement of the ideal gas law, but it has later been corrected in statistical thermodynamics. Again we have a case of increasing truthlikeness with reference invariance: instead of thinking that Boyle –Mariotte law refers to ideal gas, it can be taken to refer to real gas, so that its claim can be compared with van der Waals law.

Darrell Rowbottom (forthcoming) argues against the definitions (3) and (4) that scientific progress is possible in the absence of increasing verisimilitude. He asks us to imagine that the scientists in a specific area of physics have found the maximally verisimilar theory C*. Then, by the criterion (3), no more progress is possible, but yet this general true theory could be used for further predictions and applications. One reply to this argument is that the definition (3) involves the idealization that knowing the complete truth C* implies knowing all the deductive consequences of C*, so that predictions from C* do not constitute any further progress. But if we give up this assumption of "logical omniscience", then the theory C* can be used for solving genuine cognitive problems by deducing new consequences from C*, and the solutions of such problems are progressive by the condition (5a).[ix] Moreover, if we accept conceptual pluralism, in Rowbottom's thought experiment it would still be possible for the physicists to achieve further progress by extending their conceptual framework in order so find a still deeper complete truths about their research domain.

Alexander Bird (2007) has advocated an *epistemic* definition of progress as increase of knowledge: even though here knowledge is not defined as justified true belief, it is taken to entail truth and justification, so that Bird's epistemic view in fact returns to the old cumulative model of progress. He argues that the *semantic* definition (accumulation of truths or increasing truthlikeness) is not sufficient to define scientific progress, so that the epistemic definition referring to justification and knowledge is more adequate. Rowbottom (2008) contends against Bird that justification is instrumental rather than constitutive of progress. Mizrahi (2013a) shows that the epistemic view is still supported by many practicing scientists, but such interviews hardly can settle a normative philosophical issue about progress.

Bird's characterization of the "semantic" view includes two alternatives which should be distinguished. Since Popper (1963) scientific realists have realized that truth alone cannot *the* aim of science, since this goal could be pursued with a conservative strategy of seeking maximally probable – even tautological – hypotheses. As Levi (1967) shows, scientists have to "gamble with truth" or risk error in their attempt to find interesting and informative truths. Perhaps accumulation of true beliefs could describe the aim of Goldman's (1999) "veritism", which is based on his reliabilist epistemology, but this is quite different from maximal verisimilitude as the aim of science.[x]

Bird argues against the semantic view by the following thought experiment. Imagine that a scientific community has formed beliefs B by an irrational method M, such as astrology, and B happens to be true. M is then shown to be unreliable and the beliefs B are given up. He goes on to suggest that for the semantic view, but not for the epistemic view which requires adequate justification, the acquisition of accidentally true beliefs by an unreliable method is progress, and the rejection of unfounded but true beliefs is regressive.

The virtue of Bird's argument is that it reveals the abstract nature of most discussions of scientific progress: a condition like (3) treats theories in terms of their semantic content but independently of their status among the scientists. A hidden assumption has been that the primary application of the notion of scientific progress concerns successive theories which have been accepted by the scientific community. Some sort of tentative justification for such theories is presupposed even by a radical fallibilist like Popper who is ready to talk about the best-tested theories so far as "the scientific knowledge" of the day (Popper, 1979, p. 261). As Lakatos vividly showed, sometimes such knowledge-seeking takes place in scientific subcommunities pursuing their own "research programmes", but even there progress requires success in experimental tests. Irrational beliefs and beliefs without any justification simply do not belong to the scope of *scientific* progress (Niiniluoto, 2014a). Further, as reminded by Cevolani and Tambolo (2013), the verisimilitude approach handles issues about justification by means of the distinction between real and estimated progress (see (3) and (4)). By (4), irrational adoption of true beliefs is not progressive, and it need not be regressive to give up such beliefs.

Estimated verisimilitude measures allow also us to handle historical cases of anticipation where a good theory is first suggested without sufficient justification and only much later is shown to be acceptable (e.g. Aristarchus on heliocentric system, Wegener on continental drift). The initial evidence E for a hypothetical theory H may be weak, so that ver(H/E) is low, and the theory H is not accepted in science, but then new evidence E' increases its expected verisimilitude and thus gives reasons to claim that H is truthlike and eventually leads to the acceptance of H.

By the results (5a) and (5c), the verisimilitude account of progress includes Bird's cumulative model as its special case. But the crucial question about Bird's epistemic approach concerns its ability to give an account of historical sequences of false theories (cf. (5f) above). He mentions the transitions from Galileo to Newton to Einstein and from Ptolemy to Copernicus to Kepler, but today we are aware that these sequences include false theories which cannot be *known* by Bird's own standards.[xi] Bird suggests that if H is approximately true then the proposition 'approximately H' or A(H) is fully true. So replace the sequence of false theories $H_1, \ldots, H_k$ by the sequence $A(H_1), \ldots, A(H_k)$ which contains fully true theories adding to the truth provided by their predecessors. The most fatal problem with this proposal concerns its difficulty in distinguishing progress and regress in science. Suppose that $H_1, \ldots, H_k$ is a regressive sequence of theories with increasing distances from the truth. By Bird's argument, even in this case the sequence $A(H_1), \ldots, A(H_k)$ would consist of true and known statements. But in spite of this cumulative knowledge on the level of A-statements, the original sequence is not progressive (see Niiniluoto, 2014a).

According to the realist views of scientific progress (such as the cumulative epistemic and non-cumulative verisimilitude approaches), science makes progress on the level of theories. Those selective realists, who identify the realist commitments of theories in those parts which are *preserved* in theory changes, have a difficulty of explaining how such theoretical progress is possible. Most accounts of selective realism have not directly addressed this conceptual question of scientific progress – but perhaps their only move is to appeal to the idea of accumulation of such selected true parts. The verisimilitude approach has no such problem with stability assumptions, since it optimistically allows that all parts of theories may be changed and improved (see Section 4).

Duhem's *instrumentalist* proposal in 1906 was that real progress occurs only slowly and constantly on the level of the empirical content of theories (see Duhem, 1954, pp. 38-39). Thus, progress means the accumulation of observational statements covered by fluctuating theories.[xii] The same cumulative idea is formulated in some empiricist accounts of reduction, where a new theory includes all the true or verified empirical consequences of its predecessor. A similar account of progress could be formulated by Bas van Fraassen's (1989) *constructive empiricism,* which demands that theories are empirically adequate, i.e. all of their observational consequences are true. While instrumentalists (like Duhem) deny that theories have truth values, axiological non-realists (like van Fraassen and Laudan) or "epistemic instrumentalists" (Stanford, 2006) do not include truth among the aims of science.

More sophisticated accounts of empirical progress admit that empirical success is often approximate, and allow that theories have besides positive successes also anomalies and failures (see Kuipers, 2000). Variants of such views include Thomas Kuhn's (1970) account of progress by *puzzle solving* (where puzzles are problems whose solutions are guaranteed by a paradigm) and Larry Laudan's (1977) notion of *problem-solving effectiveness* (the number of solved problems minus the anomalies and generated conceptual problems).

For Laudan, solving an empirical problem means that a "statement of the problem" is deduced from a theory (Laudan, 1977, p. 25). This agrees with Hempel's DN-model of potential explanation which answers questions of the form "Why p?" by deducing p from a theory (with initial conditions). Laudan attempts to distinguish his notion from explanation by noting that solutions of empirical problems are often approximate, but this seems to forget that already Hempel and Popper analyzed approximate DN-explanations, where a theory entails a statement p' approximating p (see Hempel, 1965, p. 344). Laudan adds that theories also anticipate nature, so that they solve predictive problems of the form "p or not p?" by deducing one of these alternatives from a theory. Thus, on the whole, Laudan's measure of the number of solved problems is equivalent to what Hempel called the *systematic power* of a theory.

Eino Kaila, who coined the term 'logical empiricism' in 1926, pointed out in 1939 that scientific theories are not just expected to entail a multitude of empirical consequences, but they should do this with as few independent postulates as possible. Kaila's notion of *relative simplicity* is thus the ratio between the systematic power of a theory and its complexity.[xiii] However, Kaila differs from Laudan (and Mach's positivist principle of economy of thought) by his thesis that relative simplicity gives empirical support to a theory. This is, indeed, one of the strategies that a scientific realist can use against antirealists like van Fraassen and Laudan: empirical success is a fallible indicator of the truth of the theory (see Section 3).

Laudan's notion of problem-solving does not include decision problems, where we choose between alternative actions, but it is clear that scientific theories are also *pragmatically successful* as guides of our actions. Applied research, often using the results of basic research, formulates rules of action which are then more or less successful in practice. Again one may claim that success in practice is an indicator of the truth of a theory, but some philosophers have proposed it as a definition of scientific progress. Thus, Nicholas Rescher's (1977) "methodological pragmatism" characterizes progress as "the increased success of applications in problem solving and control". A similar proposal by Heather Douglas (2014) defines progress as "the increased capacity to predict, control, manipulate, and intervene in various contexts".

Douglas argues that a clear sense of scientific progress can be provided, if we "relinquish" the distinction between pure and applied science. However, she does not distinguish between science (pure or applied) as knowledge-seeking and technology as (science-based) design of tools and artifacts. For a critical realist, this yields a confusion between scientific progress and technological progress (see Niiniluoto, 1984, Ch. 12).

3. Success without Miracles

Both Kuhn and Laudan admitted that they cannot explain why science is an effective instrument of prediction, control, and problem solving.[xiv] Since the 1950s the most popular alternative among the scientific realists (among them Jack Smart, Hilary Putnam, Grower Maxwell, and Richard Boyd) is to defend realism as the best hypothesis which explains the practical (empirical and pragmatic) success of science. According to the "ultimate argument" (cf. Musgrave, 1988) or "no miracle argument for scientific realism" (NMA), the ability of scientific theories to explain surprising phenomena and to yield correct empirical predictions and effective rules of action would be a "cosmic coincidence" or a "miracle" unless they refer to real things and are true or at least approximately true or truthlike (see Psillos 1999).

Kuhn guessed that his inability to explain scientific success is related to the difficulty of solving the problem of induction, but it is more appropriate to consider here *abduction*, which Peirce introduced as the third mode of reasoning besides deduction and induction (see Niiniluoto, 1999b). Induction as such cannot reason from empirical evidence to conclusions about theoretical entities; this is the task of hypothetical or abductive reasoning from effects to causes, or from observational data to hypothetical explanatory theories:

(A) The surprising fact E is observed;
But if H were true, E would be a matter of course.
Hence, there is reason to suspect that H is true.

(*CP* 5.189). According to Peirce, against Comte's positivism, abduction "frequently supposes something which it would be impossible for us to observe directly" (*CP* 2.640). Peirce understood that this form of inference is fallible and open to errors. Therefore, he added, in science the abductive step is followed by severe observational and empirical tests of the deductive or probable consequences the hypothesis (*CP* 2.634). Thus, a good hypothesis should have both explanatory and predictive power (see also Whewell, 1840). It is clear that NMA as a defence of scientific realism is an abductive argument (see Niiniluoto 1984, p. 51).

Peirce himself analysed abduction in terms of truth-frequencies, but as a method of confirmation abduction also has a straightforward Bayesian justification: if theory H entails evidence E or makes E more probable, then E *confirms* H by increasing its epistemic probability. Thus, if theory H deductively or inductively explains E, then E confirms H in the sense of positive relevance, i.e. $P(H/E) > P(H)$. This result is generally applicable to theories which may include explanatory assumptions about unobservable entities. The only way of blocking this reasoning is to assume that all theories have a priori the probability zero (see van Fraassen, 1989), but this amounts to a dogmatic scepticism about theories. Moreover, cases of sharp hypotheses where the assumption $P(H) = 0$ is legitimate, can be handled by the tools of approximate truth and truthlikeness.

The notion of confirmation is still weak in the sense that the same evidence may confirm several conflicting hypotheses. In such cases of underdetermination, it may be reasonable to suspend judgment for a while and search for more detailed evidence by new observations, experiments, and instruments. Stronger forms of abduction interpret Peirce's schema (A) as a rule of *acceptance* or *inference to the best explanation:*

(IBE) Hypothesis H may be inferred from evidence E, if H is a better explanation of E than any other rival explanation.

If a critical realist proposes IBE is as an explication of what Laudan (1984) called the "upward path" from empirical success to approximate truth, it is important to study the reformulation of abductive inference (A) where its conclusion concerns the truthlikeness of a hypothetical theory on the basis of its success in explanation and prediction (see Kuipers 2000; Niiniluoto 2004, 2011). For example, the success of Newton's theory in engineering applications is due to the truthlikeness of its axioms. Thus, *inference to the best theory* can be formulated by the rule:

(IBT) If theory H is the best explanation of evidence E, conclude for the time being that H is truthlike.

The strength of IBT can be assessed by the function ver, which gives a fallible indicator or link between the empirical success of a theory and its estimated truthlikeness It is reasonable to require that an acceptable hypothesis is "sufficiently good" (Lipton, 2004). Minimally, this means that the best hypothesis in IBT should be more truthlike than a tautology (i.e. better than ignorance).

In a general form the *no miracle argument* looks like the following:

(NMA) Many theories in science are empirically successful.

The truth or truthlikeness of scientific theories is the best explanation of their empirical success.

Hence, conclude that such successful theories are truthlike.

The first premise about the success of science is accepted both by realist and antirealists, even though in particular cases the attribution of success to a specific theory may be non-trivial. As a whole, the argument NMA involves something like the principle IBT, and the conclusion supports the position of critical scientific realism. The no miracle argument as a reply to Laudan's challenge presupposes a minimal realist framework where it makes sense to assign truth values to scientific statements (including theoretical postulates and laws). Besides semantic realists, this framework is accepted by such methodological and epistemological antirealists who think that the truth of theories is an irrelevant (van Fraassen, 1989) or "utopian" aim (Laudan, 1984) which "exceeds our grasp" (Stanford, 2006). If successful, the no miracle argument is also relevant to those semantic antirealists and instrumentalists whose inclination to treat theories as schemata without truth values is motivated by their belief about the inaccessibility of theoretical truth.

Kuipers notes that the premise of IBT, unlike its conclusion, is comparative between rival theories. Therefore, one may formulate weaker comparative versions of these inferences:

(IBT^c) If H' is a better explanation of evidence E than H, conclude that H' is more truthlike than H.

(NMA^c) Theory H' is empirically more successful than its rival H.

That H' is more successful than H can be explained by the assumption that H' is more truthlike than H.

Hence, conclude that H' is more truthlike than H.

For example, on the whole the special theory of relativity is able to explain several phenomena more accurately than classical mechanics, so that by IBT^c it is more truthlike than Newton's theory. A comparative rule like IBT^c is cautious in the sense that in seeking the most truthlike of the available hypotheses it avoids van Fraassen's (1989) problem of a "bad lot".[xv]

The crucial second premise of NMA needs a reply to Laudan's challenge of showing that there is a "downward path" from approximate truth to empirical success. For true theories, scientific realists have an easy answer: if a theory is true, then all of its deductive empirical consequences (if any) are true as well. For truthlike theories, the matter is more complicated, but still closeness to theoretical truth is sufficient to guarantee at least approximate, average, and probable empirical and pragmatic success (see Niiniluoto, 1984, pp. 179-183; Kuipers, 2014). Further, attempts to give antirealist explanations of the success of science on the basis of pragmatism or constructive empiricism have failed. For example, Arthur Fine (1986) has argued that in the explanatory schema "theory H is empirically successful, because H is truthlike" an instrumentalist or anti-realist can replace the realist notion of truth by the pragmatist notion of truth. But, as the pragmatist defines truth as pragmatic success, Fine's suggestion would turn this schema into a non-explanatory tautology "theory H is pragmatically successful, because H is pragmatically successful". Similarly, if truth is replaced by van Fraassen's notion of empirical adequacy (see Lyons, 2003), the schema "theory H is pragmatically successful, because H is empirically adequate" again fails to be explanatory, since it would "explain" the truth of some of the empirical consequences of H by the truth of all such consequences.

Laudan (1984) and van Fraassen (1989) have also suggested that no explanation of the success of scientific theories is needed, since theories are selected for survival by their success. This evolutionary move is not convincing, either, since it fails to point out any characteristic permanent feature of our best theories (such as their truthlike correspondence to reality) which accounts for their ability to yield successful explanations and predictions. It is a different matter to describe the selection processes which gives us empirically successful theories and to explain why such theories are (and continue to be) successful. Hence, it seems that realism is the best and the only explanation of such empirical success (see Niiniluoto, 1999a, pp. 197-199; Psillos, 1999).[xvi]

4. Pessimism and Optimism about Scientific Progress

Kuhn stated that he is a "convinced believer in scientific progress" (Kuhn, 1970, p. 206), but the key premise was his own antirealist puzzle-solving account of progress. Antirealists turn into pessimists if they try to analyze progress in realistic terms. A famous "metainduction" was formulated by Putnam (1978), p. 25: "just as no term used in the science of more than fifty (or whatever years) ago referred, so it will turn out that no term used now refers". In his "confutation of convergent realism", Laudan (1984) used this *pessimistic metainduction* (PI) to infer from the premise that many theories in the history of science (e.g. ether and caloric theories) have been non-referring and false but yet to some extent empirically successful to the conclusion that this is the fate of our current and future theories as well. One may question, whether this historical argument satisfies the conditions for a valid or reliable induction. But many philosophers have shared Laudan's pessimism, in most cases against formulations of Psillos (1999), by giving historical examples of past theories which had some empirical success, including novel successes in relation to their predecessors, but still are non-referring and false by present lights. The realists have developed several selective responses to PI which e.g. restrict realist claims to mature theories, to theories enjoying novel predictive success, or those theoretical parts which feature in an essential way in the derivation of novel predictions (see Ladyman, 2002). Chakravartty (2007), p. 47, argues on the basis of his semirealism that realists can assert "an optimistic induction on the parts of theories to which they commit, to the extent that these parts tend to survive over time". But, against the claims of such "preservative" or "localized" realism, it has been argued that such successes may have been based upon theoretical postulates that are discredited today (see Chang 2003; Elsamahi 2005; Lyons 2006; Stanford 2006).

Our discussion above has already outlined the most promising realist approaches to the pessimistic metainduction. Instead of emphasizing those stable parts of theories which survive over time, our picture of theory-change is dynamic in the sense that all parts of current theories may be improved by increasing their truthlikeness. In Section 2, we have seen that rival successive theories can be treated as referring to the same theoretical entities so that it makes sense to compare their degrees of truthlikeness. No epistemic scepticism can defeat the possibility of such real progress in science, but we have also grounds for claiming that science has been and will be progressive. Instead of using single theories in Laudan's list as instances of a metainduction, one should consider *pairs* of theories as such instances. For example, phlogiston theory was more truthlike than its predecessors, which treated fire as a substance rather than as a process, and it was superseded by a more truthlike oxygen theory (see Niiniluoto, 1999a, pp. 191-192; Schurz, 2011), and similarly old quantum theory was more successful than classical mechanics (see Kuipers, 2000, pp. 278-288). Doppelt (2014) has given an overoptimistic interpretation that the rejection of past theories presupposes that our best current theories are *true* (so that (5d) would be the typical theory sequence). A critical realist may instead grant that future theories are false, since sequences of type (5f) are common in the history of science. However, without simply concluding that future theories are *false*, the realist can argue that in typical cases the successor theory is *more truthlike than its predecessor*. The fact that such theories have been replaced by better theories is not a "Pyrrhic victory" for scientific realism (see Stanford 2006), since it supports the realist picture of scientific progress as increasing truthlikeness. Indeed, every instance of the original PI supports the progressive nature of science.

Evidence for such a comparative and dynamic picture of successful science comes not only from an optimistic historical induction from past science, but also from the fact that scientists by their method favour empirically successful theories and the increasing success of such theories is best explained by their increasing truthlikeness. Thus, Theo Kuipers (2009) suggests on the basis of NMA[c] that “comparative realism is the best answer to antirealism”. Also Moti Mizrahi (2013b) defends “relative realism” by assuming that the assessment of theoretical hypotheses is always comparative (but without appealing to NMA).[xvii] David Harker (2013) too argues that an important victory over many forms of antirealism is obtained by showing that lineages of theories are becoming more truthlike rather than claiming that they are approximately true. Harker’s version of selective realism restricts the realist attitude to those parts of theories that generate comparative progress and predicts that such parts are retained in the development of science.

PI has been interpreted as refuting the explanatory connection between truthlikess and empirical success. In Section 3, we have defended this connection and argued instead that even the modest success of some theories (such as phlogiston theory) has to be explained by the fact that parts of these theories were close to the truth – and no alternative explanation is available.

Comparative realism is epistemically cautious, as it admits that we never know for sure how close to the truth we have progressed. It agrees with Popper’s strong fallibilism that “while we *cannot* ever have sufficiently good arguments in the empirical sciences for claiming that we have actually reached the truth, we *can* have strong and reasonably good arguments for claiming that we may have made progress toward the truth” (Popper, 1979, pp. 57-58). It need not disagree with Kyle Stanford’s (2006) predicament that recurrently the scientists have failed to exhaust all the possible hypotheses. But the potential existence of “unconceived alternatives”, which may be equally well supported as our currently best one, need not lead to a theoretical scepticism about atoms, genes, gravitational fields, and the past ancestors of our species (*ibid*., p. 210). On the contrary, the realist need not believe that our current descriptions of theoretical entities are final and literally true, but progress can still be made with the advance of theories and evidence for them. In this sense, the fact that truth has not yet been found gives hope for optimism: perhaps still better and deeper theories can be reached when we move to new and richer conceptual frameworks.

Stronger form of realism appeal to the original non-comparative form of IBE or NMA to conclude that our best theories are in fact in the proximity of truth – at least so close that it is rational to tentatively accept them in our evolving body of scientific knowledge and to use them as a basis of practical action. But even such forms of realism leave room for further progress.

An old story relates that, when seeing that a glass is partly filled with water, an optimist states that it is half full and a pessimist that it is half empty. Scientific realists and antirealists see the same facts about the historical development and practices of science, but give conflicting – optimistic and pessimistic - interpretations of them. In this paper, I have tried to summarize some reasons for an optimistic realism.

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BIBLIOGRAPHY

Aronson, J. L., Harré, R. and Way, E. C. (1994). *Realism Rescued: How Scientific Progress is Possible,* London: Duckworth.

Bird, Alexander (2007). "What Is Scientific Progress?", *Nous* **41**, 92-117.

Bird, Alexander (2008). "Scientific Progress as Accumulation of Knowledge: A Reply to Rowbottom". *Studies in History and Philosophy of Science Part A* **39**, 279-281.

Cevolani, Gustavo and Tambolo, Luca (2013). "Progress as Approximation to the Truth: A Defence of the Verisimilitudinarian Approach", *Erkenntnis* **78**, 921-935.

Chakravartty, Anjan (2009). *A Metaphysics for Scientific Realism: Knowing the Unobservable,* Cambridge: Cambridge University Press.

Chang, Hasok (2003), "Preservative Realism and Its Discontents: Revisiting Caloric". *Philosophy of Science* **70**, 902-912.

da Costa, Newton and French, Steven (2003). *Science and Partial Truth,* New York: Oxford University Press.

Diéguez, Antonio (2011). "Kitcher's Modest Realism: The Reconceptualization of Scientific Objectivity", in Wenceslao Gonzalez (ed.), *Scientific Realism and Democratic Society: The Philosophy of Philip Kitcher*, Amsterdam: Rodopi, pp. 141-169.

Doppelt, Gerard (2014). "Best Theory Realism", *European Journal of Philosophy of Science* **4**, 271-291.

Douglas, Heather (2014). "Pure Science and the Problem of Progress". *Studies in History and Philosophy of Science Part A* **46**, 55-63.

Duhem, Pierre (1954). *The Aim and Structure of Physical Theory*. Princeton: Princeton University Press.

Elsamahi, Mohamed (2005). "A Critique of Localized Realism", *Philosophy of Science* **72**, 1350-1360.

Fine, Arthur (1986). "Unnatural Attitudes: Realist and Instrumentalist Attachments to Science", *Mind* **95**, 149-179.

Frost-Arnold, Greg (2014). "Can the Pessimistic Induction be Saved from Semantic Anti-Realism about Scientific Theory", *The British Journal for the Philosophy of Science* **65**, 521-548.

Giere, Ronald (2006). *Scientific Perspectivism*, Chicago: The University of Chicago Press.

Goldman, Alvin I. (1999). *Knowledge in a Social World*, Oxford: Clarendon Press.

Haack, Susan (2007). *Defending Science – Within Reason*, New York. Prometheus Books.

Harker, David (2013). "How to Split a Theory: Defending Selective Realism and Convergence without Proximity", *The British Journal for the Philosophy of Science* **64**, 79-106.

Hettema, H. and Kuipers, T. (1995). "Sommerfeld's *Atombau*: A Case Study in Potential Truth Approximation", in Theo Kuipers and A. N. Mackor (eds.), *Cognitive Patterns in Science and Common Sense*, Amsterdam: Rodopi, pp. 272-297.

Horowicz, T. and Janis, A. S. (1994). *Scientific Failures*, Lanham: Rowman and Littlefield.

Kaila, Eino (2014). *Human Knowledge – A Classic Statement of Logical Empiricism*, La Salle: Open Court.

Kitcher, Philip (1993). *The Advancement of Science: Science without Legend, Objectivity without Illusions*, Oxford University Press, Oxford.

Kitcher, Philip (2001). *Science, Truth, and Democracy*, Oxford University Press, New York.

Kuhn, Thomas (1970). *The Structure of Scientific Revolutions*, 2nd ed. Chicago: The University of Chicago Press.

Kuhn, Thomas (1978). *The Essential Tension*, Chicago: The University of Chicago Press.

Kuipers, Theo (2000). *From Instrumentalism to Constructive Realism: On Some Relations between Confirmation, Empirical Progress, and Truth Approximation*, Dordrecht: Kluwer.

Kuipers, Theo (2009). "Comparative Realism as the Best Response to Antirealism", in Clark Glymour, Wang Wei, and Dag Westerståhl (eds.), *Logic, Methodology and Philosophy of Science: Proceedings of the Thirteenth International Congress*, London: King's College Publications, pp. 221-250.

Kuipers, Theo (2014). "Empirical Progress and Nomic Truth Approximation Revisited", *Studies in History and Philosophy of Science* **46**, 64-72.

Kukla, André (1998). *Studies in Scientific Realism*, New York: Oxford University Press.

Ladyman, James (2002). *Understanding Philosophy of Science*, London: Routledge.

Laudan. Larry (1977). *Progress and Its Problems: Toward a Theory of Scientific Growth*, London: Routledge and Kegan Paul.

Laudan, Larry (1984). *Science and Values: The Aims of Science and Their Role in Scientific Debate*, Berkeley: The University of California Press.

Levi, Isaac (1967). *Gambling with Truth: An Essay on Induction and the Aims of Science*, New York: Alfred A. Knopf.

Lipton, Peter (2004). *Inference to the Best Explanation*, 2nd ed., London: Routledge.

Lyons, Timothy (2003). "Explaining the Success of a Scientific Theory", *Philosophy of Science* **70**, 891-901.

Lyons, Timothy (2006). "Scientific Realism and the Stratagema de Divide et Impera", *British Journal for the Philosophy of Science* **57,** 537-560.

Mäki, Uskali (ed.) (2002). *Fact and Fiction in Economics: Models, Realism, and Social Construction*, Cambridge: Cambridge University Press.

Mizrahi, Moti (2012). “Why the Ultimate Argument for Scientific Realism Ultimately Fails?”, *Studies in History and Philosophy of Science* **43**, 132-138.

Mizrahi, Moti (2013a). “What is Scientific Progress? Lessons from Scientific Practice”, *Journal for General Philosophy of Science* **44**, 375-390.

Mizrahi, Moti (2013b). “The Argument from Underconsideration and Relative Realism”, *International Studies in the Philosophy of Science* **27**, 393-407.

Musgrave, Alan (1988). “The Ultimate Argument for Scientific Realism”, in Robert Nola (ed.), *Relativism and Realism in Science*, Dordrecht: Kluwer, pp. 229-252.

Niiniluoto, Ilkka (1984). *Is Science Progressive?*, Dordrecht: D. Reidel.

Niiniluoto, Ilkka (1987). *Truthlikeness,* Dordrecht: D. Reidel,

Niiniluoto, Ilkka (1999a). *Critical Scientific Realism,* Oxford: Oxford University Press.

Niiniluoto, Ilkka (1999b). “Defending Abduction”, *Philosophy of Science (Proceedings)* **66,** S436-S451.

Niiniluoto, Ilkka (2004). “Truth-seeking by Abduction”, in Friedrich Stadler (ed.), *Induction and Deduction in the Sciences*. Dordrecht: Kluwer, pp. 57-82.

Niiniluoto, Ilkka (2007). “Evaluation of Theories”, in Theo Kuipers (ed.), *Handbook of Philosophy of Science: General Philosophy of Science - Focal Issues,* Amsterdam: Elsevier, pp. 175-217.

Niiniluoto, Ilkka (2011). “Revising Beliefs Towards the Truth”, *Erkenntnis* **75**, 165-181.

Niiniluoto, Ilkka (2012). “Scientific Progress”, *www.oxfordbibliographies.com*.

Niiniluoto, Ilkka (2014a). “Scientific Progress as Increasing Verisimilitude”, *Studies in History and Philosophy of Science* **46**, 73-77.

Niiniluoto, Ilkka (2014b). “Scientific Realism – Independence, Causation, and Abduction”, in Kenneth Westphal (ed.), *Realism, Science & Pragmatism*, London: Routledge.

Niiniluoto, Ilkka (2014c). “Against Relative Truth”, in Kevin Mulligan, Katarzyna Kijania-Placek and Tomasz Placek (eds.), *The History and Philosophy of Polish Logic: Essays in Honour of Jan Wolenski*, Houndmills: Palgrave Macmillan, pp. 141-159.

Niiniluoto, Ilkka (2015). "Scientific Progress", in E. Zalta (ed.), *The Stanford Encyclopedia of Philosophy*, http://plato.stanford.edu.

Nowak, Leszek (1980). *The Structure of Idealization*, Dordrecht: D. Reidel.

Oddie, Graham (1986). *Likeness to Truth*, Dordrecht: D. Reidel.

Oddie, Graham (2014). "Truthlikeness", in E. Zalta (ed.), *Stanford Encyclopedia of Philosophy*, http://plato.stanford.edu.

Peirce, Charles S. (1931-35). *Collected Papers* 1-6, ed. by C. Hartshorne and P. Weiss, Cambridge, MA: Harvard University Press.

Piscopo, C. and Birattari, M. (2010). "A Critique of the Constitutive Role of Truthlikeness in the Similarity Approach", *Erkenntnis* **72**, 379-382.

Popper, Karl R. (1963). *Conjectures and Refutations: The Growth of Scientific Knowledge*, London: Hutchinson.

Popper, Karl R. (1979). *Objective Knowledge: An Evolutionary Approach* (2nd ed.), Oxford: Oxford University Press.

Psillos, Stathis (1999). *Scientific Realism: How Science Tracks Truth*, London: Routledge.

Psillos, Stathis (2009). *Knowing the Structure of Nature: Essays on Realism and Explanation*, Houndmills: Palgrave Macmillan.

Putnam, Hilary (1978). *Meaning and the Moral Sciences*. London: Routledge and Kegan Paul.

Putnam, Hilary (1981). *Reason, Truth, and History*. Cambridge: Cambridge University Press.

Rowbottom, Darrell (2008). "N-Rays and the Semantic View of Scientific Progress", *Studies in History and Philosophy of Science* **39**, 277-278.

Rowbottom, Darrell (forthcoming). "Scientific Progress without Increasing Verisimilitude: In Response to Niiniluoto", *Studies in History and Philosophy of Science*.

Ruetsche, Laura (2011). *Interpreting Quantum Theories*, Oxford: Oxford University Press.

Schurz, Gerhard and Weingartner, Paul (2010). "Zwart and Franssen's Impossibility Theorem Holds for Possible-worlds Accounts but not for Consequence-accounts to Verisimilitude", *Synthese* **172**, 416-436.

Schurz, Gerhard (2011), "Structural Correspondence, Indirect Reference, and Partial Truth: Phlogiston Theory and Newtonian Mechanics", *Synthese* **180**, 103-120.

Sellars, Wilfrid (1968). *Science and Metaphysics*, London: Routledge and Kegan Paul.

Stanford, P. Kyle (2006). *Exceeding Our Grasp: Science, History, and the Problem of Unconceived Alternatives*, Oxford: Oxford University Press.

Tambolo, Luca (2014). "Pliability and Resistance: Feyerabendian Insights into Sophisticated Realism", *European Journal for Philosophy of Science* **4**, 197-213.

van Fraassen, Bas (1989). *Laws and Symmetry*, Oxford: Oxford University Press.

Whewell, William (1840). *Philosophy of the Inductive Sciences*, London: Parker & Sons.

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[i] Aronson, Harré and Way (1994) operate with a weaker notion of approximate truth which has a maximal value if T is true, i.e. T is entailed by C*.

[ii] For an alternative approach to epistemic truthlikeness, see Kuipers (2000).

[iii] This objective notion of truth distinguishes critical realism from Ron Giere's (2006) recent formulation of *perspectival realism*, which allows only a theory-relative notion "according to this highly confirmed theory (or reliable instrument), the world seems to be roughly such and such".

[iv] One way of achieving this aim would be to find a categorical theory which is able to determine the structure of the world up to isomorphism. This task is very ambitious, since no first-order theory is categorical. It is also known that quantum field theory in thermodynamic limit (with infinite number of degrees of freedom) has non-isomorphic models (Ruetsche, 2011).

[v] For references, see the bibliographical survey in Niiniluoto (2012).

[vi] For examples, see Horowicz and Janis (1994). Blondlot's non-existent N-rays gives also an example of scientific regress (see Bird, 2008; Rowbottom, 2008).

[vii] If we assume with metaphysical realism that the world has a definite structure, which can be described in a Peirceish framework P, then progress can be defined by truthlikeness relative to such framework P. In particular, if the ultimate goal is to know the unique structure of the world, as ontic structural realists think, then the appropriate measure of progress can be given by partial isomorphisms (see da Costa and French, 2002, for an account of partial truth).

[viii] Rowbottom (forthcoming) argues that increasing theoretical verisimilitude is not the central dimension of scientific progress, since achieving predictive power and understanding could be taken to be the primary goals of science. I agree that predictive power and understanding are important, but they can be maximized by maximizing verisimilitude, but not necessarily vice versa.

[ix] This is what Kuhn (1970) called "puzzle-solving".

[x] For a reliabilist, theories are justified with epistemic processes which have a high truth-frequency in producing true results.

[xi] The classical notion of knowledge, which presupposes truth and justification, cannot cover false theories (e.g. Newton's mechanics). For a modified notion of conjectural knowledge, where truth is replaced by truthlikeness, see Niiniluoto (1999a), p. 84. Progress with respects to such conjectural knowledge is not cumulative.

[xii] Duhem added to his instrumentalism the claim that physical theory makes progress by becoming "more and more similar to a natural classification which is its ideal end" (Duhem, 1954, p. 298). One may wonder whether such a peculiar form of convergent realism makes sense without assuming that the classified laws refer to real theoretical entities.

[xiii] For a translation of Kaila's work, published originally in Finnish and Swedish in 1939, see Kaila (2014).

[xiv] See Kuhn (1978), pp. 332-333, Laudan (1977), p. 224.

[xv] Van Fraassen argues that the true hypothesis is missed if it is not included among the considered rivals. But one can always operate with a partition of mutually exclusive and logically exhaustive hypotheses so that their set must contain a true one. If the best one turns out to be the catch-all hypothesis (in the simplest case, the negation ¬H of H), we have reason to find a richer set of hypotheses.

[xvi] Mizrahi (2012) argues that Kukla's (1998) "weak surrealism" (i.e. the observable world behaves as if our mature theories are true) and realism (i.e. our mature theories are true) are equally plausible as explanations for the success of science, since they yield the same independently testable predictions. However, weak surrealism only describes the fact about science which is in need of explanation.

[xvii] This is not quite convincing. The best justification of induction is not only comparative, but shows that the inductive probability of the strongest hypothesis approaches one with increasing evidence. A similar result holds in special cases also for the convergence of the estimated verisimilitude (see Niiniluoto, 2007).