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Reevaluating Inductive Reasoning: A Contemporary Approach Based on William Whewell's Induction

Reevaluando el razonamiento inductivo: un enfoque contemporáneo basado en la inducción de William Whewell

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Abstract

Traditional attempts to understanding inductive reasoning in science have typically involved analyzing language, focusing on statements or propositions. However, recent arguments suggest that this approach misconceives induction, prompting the need for a new perspective. This study offers a fresh view on induction by integrating William Whewell's theory of induction, which distinguishes two forms of reasoning: interpretation and representation. This perspective suggests that induction can be seen as a reasoning process based on semantic and pragmatic models rather than statements or propositions.

Keywords: induction, inductive reasoning, scientific practice, models, Whewell's induction.

Resumen

Tradicionalmente, los intentos de comprender el razonamiento inductivo en la ciencia se han centrado en un análisis con base en enunciados o proposiciones. Sin embargo, argumentos recientes sugieren que este enfoque constituye un error y plantean la necesidad de una nueva perspectiva. Este estudio ofrece una nueva visión de la inducción a partir de la teoría de la inducción de William Whewell con base en dos formas de razonamiento: la interpretación y la representación. Esta

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perspectiva sugiere que la inducción puede verse como un proceso de razonamiento que utiliza modelos semánticos y pragmáticos modernos, en lugar de enunciados o proposiciones.

Palabras clave: inducción, razonamiento inductivo, práctica científica, modelos, inducción de Whewell.

1. Introduction

Despite its role in the reasoning underlying the formulations of scientific hypotheses or theories, as well as their confirmation methods, induction has also been viewed by philosophers and logicians as flawed reasoning, i.e., as an invalid argument or an inference that does not preserve truth. This is because, as is well known, its conclusions extend beyond the premises, resulting in uncertain or merely probable statements (Baker 1957; Salmon 1967; Wright 1965).

The debate over the lack of validity of inductive arguments and the uncertainty of their conclusions had significant consequences for twentieth-century philosophy of science. One of these consequences was the inclination of part of the tradition to reject the analysis of scientific discovery because, although the inventive process behind scientific discoveries is guided and psychologically driven by prior knowledge of certain facts, these facts do not logically determine the outcomes (Hempel, 1996). Some believed that if induction, an invalid form of reasoning, underlies scientific discoveries, then a logical analysis of scientific discovery would be impossible. This perspective relegates such occurrences to a realm that does not permit rational analysis, similar to fleeting thoughts and moments of inspiration.

Another consequence of this line of thinking was the division of twentieth-century philosophers of science into at least two groups regarding induction: deductivists and justificationists (Barroso 2016; 2023). The former group rejected induction as the type of reasoning that underlies the construction of scientific hypotheses and theories, as well as any belief in everyday life (Popper 2002; Musgrave 1999; 2012; Watkins 1984). In contrast, the latter accepted induction as a certain type of argument or inference that, while uncertain, is crucial for grasping the empirical basis of science. They advocated for the use of induction in scientific practice, either based on a set of justification rules or principles (Feigl 1981) or grounded in mathematical theories such us probability and statistics (Carnap 1945; 1950; Reichenbach 1957; 1949). Despite their discrepancies, both deductivists and justificationists adhere to a linguistic, or enunciative, approach to dealing with induction.

The introduction of semantic and pragmatic notions of models in the philosophy of science debate during the second half of the twentieth century relegated the reflection on the role of induction, pushing it away from other issues considered more central by the 'new' model-based perspective: the characterization of models, scientific representation, among others. With a few exceptions, philosophers following the model-based conception of science do not appear as concerned with induction as their counterparts in the first half of the twentieth century.

However, scientists have continued to use inductive reasoning in their work, i.e., they have continued to extend and consolidate scientific knowledge through their observations and experiments to produce better representations of the world. If induction has maintained its active role in scientific practice, why have philosophers not paid attention to this kind of reasoning within semantic and pragmatic approaches to science?

One reason for the disinterest of contemporary philosophers in induction may be that they have given up trying to solve the so-called problem of induction. One of the most difficult problems to solve in the philosophy of science is what Donald Williams dramatically called "the tragic puzzle of induction" (Williams 1948, p. 227), i.e., the problem of justifying our inductive beliefs. Why do we believe, for example, that laws of motion that explain events such as rotation, daily sunrise and sunset, will continue to work in the future?

Since for deductivists like Popper, induction does not exist but is a myth, I will only consider the justification strategies in this article. Justificationists believed that the validity of inductive beliefs lies in their occurrence in the past. However, such an answer, far from guaranteeing future events, only suggests our expectations about the future. Thus, the justification of induction for them became a search for criteria to establish beliefs, whether subjective or objective, based on - logically imperfect - inductive inferences. Recently, a third group of philosophers, inspired by John Norton (2003, 2005, 2014, 2021), has advocated a material approach to induction. According to which the inductive support for beliefs is justified materially and locally, i.e., by inferences draw from specific facts that support them.

However, none of the aforementioned alternatives has been able to adequately justify inductive inferences, as they often result in circular reasoning or an endless regress.

A second reason for contemporary philosophers' skepticism toward induction may stem from the bias in twentieth-century philosophy of science against the context of discovery, deemed incapable of logical explanation: It was then believed that if induction was considered a logically invalid form of argument or inference, a logical analysis of scientific invention practices would be unfeasible. In efforts to reexamine the analysis of ampliative inferences within the scientific discovery context, some philosophers, following Charles Peirce's lead, have argued that it is not induction but abduction - along with its counterpart, inference to the best explanation (IBE) – that form the basis for advancing our understanding of the world. Hence, they posit that the study of abduction offers a solution beyond an exhaustive treatment of induction.

Nonetheless, the question remains whether abduction is a form of inference or merely an instinct (Minnameier 2017, p. 183; Park 2017, p. 134) shared not only by scientists but also by society at large, animals, some bacteria, and even brain cells, as recent studies suggest (Magnani 2001; 2007; 2010). It is also unclear whether abduction represents a distinct form of reasoning separate from induction. The relationship between abduction and induction remains poorly understood (Flach and Kakas 2000). Some scholars advocate integrative interpretations in which induction derives its epistemic guarantee from being a type of abductive reasoning (Harman 1965; Josephson and Josephson 1994; Lipton 1991). Conversely, others argue that abduction, in combination with IBE, constitutes a specific form of inductive reasoning (Michalski 1987, 188; Sugden 2009; Earman 1992; Bird 1998; 2005; Van Fraassen 1989).[1]

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[1] In this sense, Flach and Kakas' advice to treat this as a matter of pragmatic choice is reasonable (Flach and Kakas 2000, p. 2). Accordingly, for the present paper, I understand abduction and IBE as notions integrated

The role of induction in the construction of scientific hypotheses or theories was rarely recognized by positivists and empiricists in the twentieth century. [2] One of the reasons for maintaining the irrelevance of induction in the field of discovery is that “inductions cannot introduce new concepts or conceptual models; they merely transfer them to new instances.” (Minnameier 2017, p. 152).

The perceived inability of induction to generate new knowledge and justify belief in our scientific hypotheses or theories originates from the same aforementioned bias, specifically, the linguistic bias in the treatment of induction. By 'linguistic bias in the treatment of induction,' I refer to the inclination to characterize induction solely as a type of inference or argument comprising statements or propositions (Barroso 2023)[3].

The linguistic bias in the treatment of induction in the philosophy of science can be traced back to nineteenth-century English inductive theories, or, more precisely, to Richard Whately's (1826) proposal to treat induction as a kind of abbreviated syllogism or enthymeme, in which the eliminated premise corresponds to the principle of the uniformity of nature. This understanding of induction was followed by John Stuart Mill, whose influence has persisted almost intact to the present day (McCaskey 2020).

As previously mentioned, the analysis of induction in the philosophy of science has typically been conducted within an argumentative or inferential framework. This approach has been tied to a particular approach to understanding scientific hypotheses or theories as collections or systems of statements or propositions. One way to illustrate how the classical or enunciative conception interprets theories and their empirical basis is to metaphorically describe theories as a 'complex spatial network' supported by empirical rules of interpretation, where 'the knots' represent scientific terms and 'the threads' encompass the definitions on one side and the fundamental and derived hypotheses on the other (Hempel 1952).

The Hempelian description of theories as networks formed by terms, definitions, and hypotheses was prevalent within the mentioned conception. From this viewpoint, both the evidence and the scientific laws or hypotheses are represented linguistically, i.e., in an enunciative manner. Furthermore, the inference of unknown and unobserved phenomena, present or future, from known and observed phenomena is traditionally presented in an inferential and argumentative fashion, i.e., relying on statements or propositions. According to this view, the statements or propositions involved in an inductive inference share a particular relationship where some form of implicit support between them is assumed, even in the absence of logical justification. Nevertheless, as a fundamental reasoning for scientists, philosophers in the early twentieth century proposed various explanations to elucidate the basis for our confidence in such inferences.

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with the notion of induction, broadly understood as non-monotonic, knowledge-expanding inference.

[2] An exception was Hans Reichenbach, who mentioned the use of induction to produce new knowledge in science (Reichenbach 1957, p. 341) and insisted that inductive methods are and " always will remain the genuine methods of scientific Discovery." (Reichenbach 1957, p. 383). The mainstream, however, held, like Peirce (CP, 5.145; CP, 5.170), that induction does not generate new ideas and plays only a marginal role in the realm of confirming or corroborating scientific hypotheses or theories (Minnameier 2017, p. 179).

[3] The reader can consider this article as the first part of the present study.

Although twentieth-century philosophers of science held differing views on the nature of positive support for inductive inferences, the idea that the support relation should be articulated in enunciative terms was unanimously accepted because most believed that scientists expressed it in their writings (Hempel 1996, p. 351).

Recently, there has been a suggestion that formal strategies aimed at resolving the problem of induction originate from a misinterpretation of inductive inferences, stemming from their portrayal as being upheld by universal and formal rules (Norton 2003, 2005). Following this line of reasoning, Norton advocates for a local and material basis for supporting inductive inferences rather than a universal and formal basis. However, it is arguable that both justificationist strategies and the contemporary proposal of material induction have fallen short in their efforts to account for induction due to their adherence to the traditional standpoint (cf. Barroso 2023).

The main issue is that, regardless of whether inductive conclusions in science are justified or disputed, or whether the material dimension of inductive supporting statements is addressed, the analysis of induction within a linguistic framework leads to the same conclusion: the impossibility of justifying the rationality of inductive methods in science. In the first and second sections, I briefly outline the proposals of the most representative members of the traditional approach to induction, namely, the attempts to justify inductive inferences using the 'validation' criterion proposed by Rudolf Carnap (1945; 1947; 1950) and the 'vindication' proposed by Hans Reichenbach (1949; 1957), as well as the recent material theory proposed by John Norton (2003; 2005; 2014; 2021). In the third section, I present the arguments that I employ to criticize the traditional analysis of induction as insufficient for representing induction in science. Finally, in the fourth section, I suggest the inductive theory of the Victorian philosopher William Whewell as an alternative for understanding induction from a different perspective.

2. Justification strategies in the analysis of induction

In the first decade of the twentieth century, many philosophers argued that the requirement of validity for inductive inferences was a misguided starting point. According to this stance, induction should not be evaluated by a criterion independent of its processes: inductive arguments should be judged based on their inductive, not deductive, nature (Urmson 1974). While it was not possible to definitively confirm a scientific hypothesis or theory, acceptance based on supporting positive instances was deemed feasible.

Consequently, one faction of the tradition sought to logically justify the inductive process, viewed as the partial verification of scientific hypotheses or theories through positive supporting instances (Carnap 1945; 1950, 1952; 1966; Kemeny 1955; 1963; Bar-Hillel 1968; Hintikka 1965; 1968). Another group contended that the rationale for induction should be pragmatic, meaning its effectiveness in formulating scientific explanations and predictions should justify it as a method (Reichenbach 1949; 1957; Salmon 1963; 1965; Feigl 1981). These two types of proposals are known as validation and vindication of induction, respectively.

In both the validation and vindication strategies, a measure of certainty was sought for evidence based on some mathematical theory of probability and/or statistics. The validation of induction through subjective probability by Rudolf Carnap and the vindication of induction through objective probability by Hans Reichenbach are two prominent justifications of induction in traditional analysis.

The criterion of meaning was defined in terms of verification methods by positivism and logical empiricism in the twentieth century. Consequently, the meaning of a proposition was determined by its cognitive significance, i.e., by its potential for verification, either by logical rules or by empirical evidence. Statements whose truth (or falsity) could not be determined based on this criterion were deemed pseudo-statements, lying outside the realm of scientific discourse. This semantic constraint resulted in empirical scientific principles and laws, as well as terms such as “atoms”, “quarks”, “bosons”, and “libido” that cannot be directly observed, being excluded from logical analysis. These challenges, among others, led to the eventual abandonment of the meaning criterion initially embraced by positivists and logical empiricists.

Carnap addressed the limitations imposed by the initial meaning criterion of logical positivism by proposing a dual language system, observational and theoretical, to introduce scientific concepts, and introduced the degree of confirmation 'c', indicating the extent to which a hypothesis 'h' is supported by positive instances 'e'; expressed as “c(h, e) = r” (Carnap 1945; 1947; 1950).

Carnap considered inductive logic a facet of semantics (Carnap 1945, p. 73). To overcome the syntactic limitations that require a scientific hypothesis or theory to be presented as a necessary outcome of the evidence, he formulated a probability statement detailing the degree to which the evidence partially implies the scientific theory or hypothesis.

Despite Carnap's efforts in providing theorems for probabilistic inference, these were only applicable to monadic predicate languages, systems expressing properties, not relations (Carnap 1945, p. 81). While most theorems and postulates were deemed correct, Carnap's approach faced challenges that impeded its implementation, some of which he acknowledged (Carnap 1945, p. 95). Many of these difficulties stemmed from his commitment to a linguistic framework for understanding induction (Barroso 2023).

Another difficulty was that Carnap's inductive logic refers only to particular statements, as these are the only ones that can be confirmed (see Kemeny 1953). In response to this limitation, Carnap chose to abandon the idea of confirming the general statements represented by inductive generalizations and instead focused on individual instances of confirmation (Carnap 1945, pp. 88-90; Barker 1957, p. 88). Despite the fact that some aspects of science can be articulated using specific statements, general statements play a crucial role in scientific theories, particularly in the classical or enunciative framework to which Carnap adheres. Although the Carnapian system does not explicitly include general statements, it presupposes them.

The situation regarding the justification of induction in science was not much improved by pragmatist attempts. In contrast to Carnap, Reichenbach did not argue for the justification of induction through the development of a logical system for the formal analysis of probabilistic statements. Instead, he based its justification on pragmatic grounds. While acknowledging that inductive reasoning involves a form of invalid inference, Reichenbach maintained that the use of induction can be justified as a method that leads to greater success in handling empirical scientific data.

According to Reichenbach, an inductive conclusion describes a fact, particularly the probability of an event's occurrence as determined by the limit of a relative frequency within an infinite sequence. Despite the fact that scientific laws, characterized by their generality, cannot be directly verified, Reichenbach contended that they could be confirmed through predictions.

Reichenbach proposed the frequentist interpretation of probability as the appropriate mathematical framework to explain inductive reasoning in science. According to this perspective, the probability of a hypothesis is determined by two frequencies: “the frequency of events within the specific class under consideration and the frequency of events within the broader class to which the probability refers” (Reichenbach 1957, p. 301). Thus, the objective is to establish the limit of relative frequency of a characteristic within an infinite sequence and then select the hypothesis or theory that appears most probable based on this probability.

While the logical transition from assigning probabilities to hypotheses or theories to accepting the one with the highest probability is not inherently justified, Reichenbach argued that the issue arises only if one incorrectly assumes that knowledge must be demonstrably true. Instead, he maintained that inductive tests do not necessarily lead to truths, but rather to probabilistic conclusions.

Moreover, Reichenbach contended that by assuming a hypothetical inductive principle such as the principle of the uniformity of nature, the probabilities of successful inductive inferences exceed those of inferences based on alternative methods. If other methods consistently yielded successful outcomes, they could themselves constitute a principle of uniformity, which could only be justified through induction.

Reichenbach's proposal faced significant criticisms. It was generally believed that his solution was inadequate because it did not fulfill its purpose of providing a genuine explanation of phenomena; instead, it only offered a quantitative measure of their occurrence. On the other hand, as Reichenbach noted, while the relative frequency limit escapes the margins of error as the observed proportion increases, the estimate limit's approximation to the truth remains uncertain. In other words, we do not know how many attempts it will take to obtain a correct or probably correct estimate for a true "long-term" conclusion, so there is no guarantee that our conclusion is the best one. It is not helpful to be told that if we continue to use frequentist probability indefinitely, we will eventually get closer to the truth. We are interested in determining whether it is reasonable to accept a scientific theory or hypothesis here and now (Barker, 1957). As Russell (2009) pointed out, frequentist probability is a statistical concept that does not provide a practical criterion for adopting a doxastic attitude toward scientific theories. It only provides mathematical data concerning the limit of its relative frequency.

3. Norton's Material Approach to Induction

Recently, John Norton (2003; 2005; 2014) pointed out that formal treatments of induction assume that inductive inferences operate under a universally applied formal scheme. This schema is similar to 'some a are b, then all a are b,' which is later interpreted in statistical or probabilistic terms. This treatment, based on a formal and universal scheme, induces the expectation that inductive inferences conform to a deductive approach in general.

Norton argues that philosophers have been unable to justify induction by appealing to formal and universal schemes. Most attempts to provide certainty to inductive inferences, whether statistical or probabilistic, by implicitly or explicitly assuming some form of uniformity principle, have failed. For this reason, he proposes abandoning the formal and universal scheme approach to induction and advocating for a reliance on facts, specifically the background factual conditions, as the foundation for ensuring such inferences (Norton 2005, pp. 25-31).

Rather than seeking to justify the conclusions of inductive inferences through logical or probabilistic rules, Norton shifts the perspective to grounding inductive inferences on the material facts that provide their guarantee.

In his illustration using bismuth, the inductive inference from 'some samples of bismuth melt at 271°C' to the generalization 'all samples of bismuth melt at 271°C' finds its justification in the material fact that samples of the same chemical element typically exhibit uniformity in their physical properties. This uniformity is underpinned by a chemical fact - specifically, that, barring exceptions like allotropes, the molecules of this element consistently feature the same structure. Consequently, one can infer that, with exceptions considered, bismuth is inherently predisposed to melting at 271°C based on its properties. Thus, the statement regarding the prevailing physical properties in most bismuth samples serves as both a declaration of a material fact and a validation of an inductive inference.[4]

Any factual statement is, as is well known, contingent: it may hold true in some instances while being false in others. The broad declaration concerning bismuth's properties is not exempt from this inherent contingency characteristic of factual or material statements. Hence, Norton posits that achieving universality in induction is unattainable (Norton 2014, p. 674). Revisiting the example of bismuth, the overarching statement regarding the properties of bismuth represents a factual element that authenticates the inductive inference concerning its melting point at a specific temperature. As a material fact, it is contingent, and consequently, its validity cannot be reduced to a logical truth, namely, a tautology or a truth by definition; hence, it cannot be conclusively demonstrated deductively. Thus, the question arises: how can such inferences be warranted?

According to Norton, what remains is to appeal to some kind of contingent truth to justify the general statement that "validates" the inductive inference. This approach involves relying on a truth that depends on the facts to which the general statement refers. However, within Norton's material theory, facts are not epistemologically separate from the inductive inferences that support them; hence, "we learn the warranting fact by further inductive inferences, which in turn have their own distinct warranting facts; and so on” (Norton 2014, p. 676).

Once again, in the bismuth example, the inference from "I observed a sample of bismuth with a melting point of 271°C" to the general statement that "most bismuths share this property" is supported by a material fact: Typically, bismuth samples have such material properties. The following statement can express this fact: "With a few exceptions, bismuths have uniform physical properties."

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[4] There is no universally applicable rule or scheme of induction; in contrast, its conclusions are relative to the material facts with which it deals. For example, the conclusion about bismuth cannot be applied to an element such as wax, since the material composition of wax varies from wax to wax. This leads to Norton's famous slogan: all induction is local (Norton 2003, p. 648).

The general justifying statement is, in turn, justified by other inferences of greater generality, such as prior knowledge of the uniformity of the atomic composition of physical elements derived from microscopic observations of the atoms of each class of physical elements. This, in turn, depends on knowledge of what is expected of the same type of physical element, and so on *ad infinitum*. This chain of reasoning continues indefinitely, with each conclusion building upon the preceding one.

Obviously, this suggests an infinite regression. However, Norton argues that unlike regression within a formal framework, the regression in his material approach to induction is benign, as it aligns with the inductive robustness of scientific methodologies (Norton 2014, p. 677). However, not everyone agrees with his viewpoint.

Philosophers have criticized Norton's material approach to induction due to its potential link to Humean skepticism: the progression into infinite regression implies an absence of outright assurance in our knowledge (Sober 1988; Kelly 2010). The regression typically halts at a juncture where a premise stems from demonstrative induction or ultimately from a universal statement (Worrall 2010). From another perspective, Peter Achinstein challenges Norton's assertion that a universal treatment of induction is unfeasible and argues that, in reality, Norton's material theory of local induction can harmoniously coexist with a formalized induction theory, such as Mill's framework (Achinstein 2010).

According to Norton, the facts that support inductive inferences are those consistently held in "a regular manner, which authorizes the inference" (Norton 2021, p. 8). Therefore, the consistent application of biological predicates such as "being mortal" or "having a circulatory system" to describe living organisms enables us to affirm the truth of the assertion "All living beings are mortal" and to deduce statements like "The author of these lines is mortal." This argument seems to hold some validity. When we accept the premise that all living creatures are mortal, we can then infer that some living creatures share this trait. Nevertheless, a challenge arises when attempting to verify the validity of general scientific statements, as these statements are often untestable. The issue lies in the absence of absolute certainty provided by the perceived regularity among known or observed facts. This uncertainty stems from our inability to conclusively determine whether these facts will remain consistent or "hospitable," as described by Norton, due to the constraints of our empirical knowledge.

In summary, Norton's material theory appears to share the same flaw as traditional theories of induction: it considers induction from a linguistic or enunciative point of view, which inevitably and unintentionally leads to a universal approach to its interpretation. Contrary to Norton's belief, the primary obstacle to fully understanding inductive strategies in science is not their formal logical approach or claim to universality but rather their adherence to an enunciative approach.

4. Critics of the enunciative approach of induction

Besides Carnap's attempt to develop a system of inductive logic, the philosophy of science has not adopted induction as the semantic foundation for empirical interpretation rules. Indeed, the tradition has regarded a semantic account of induction as insufficient (Sprenger 2011, p. 236). Historically, induction has been perceived as a pseudo-logical link present within arguments or inferences, rather than as an extralogical connection between theoretical terms and corresponding facts. Consequently, as Norton observed, traditional analyses of induction have favored formal treatment at the expense of its material scope.

Despite Carnap's inclination towards semantic analysis, he drew a clear demarcation between the material and formal aspects of language, deeming the latter epistemologically superior. Hempel contended that "semantics does not enable us to decide whether the theoretical terms in a given system T' do or do not have semantical, factual, or ontological reference." (Hempel 1965, p. 217).

From a traditional standpoint, it is believed that if a scientific hypothesis or theory is tested or verified, then the entities it implies are real. This suggest that truth could be formally evaluated as a relationship between the premises and their conclusions. As a consequence, truth was removed from its 'natural habitat,' semantics, and placed in an unfamiliar domain, syntax. This was a common fallacy in classical induction analysis.

Carnap's attempt to account for induction was unsuccessful because he combined intensional semantics with the logical relation of implication. While intensional semantics focuses on the (intensional) meaning of scientific terms and statements rather than their extension or reference, the logical relation of consequences plays a central role in deriving observational statements from scientific principles and laws. Combining intensional meaning and logical consequence led Carnap to represent induction as a semantic link between the premises and their conclusions (the degree of confirmation c*), thereby misinterpreting the semantic function of induction as a form of deductive reasoning—i.e., inferential reasoning based on statements or propositions. Similarly, Reichenbach's work makes a comparable error, *mutatis mutandis*.

Norton deserves credit for highlighting the material dimension and reintroducing induction into contemporary debate; however, his proposal is hindered by his implicit adherence to the enunciative treatment of induction.

Ian Hacking (1975, p. 134) noted that traditionally, induction has been approached through a linguistic lens, seen as (i) a connection between statements, and (ii) a formal scheme of reasoning claiming global or universal application. Critics like Norton and advocates of the local approach to induction have contested point (ii), while point (i) has largely escaped the attention of philosophers of science.

Due to the failure of traditional attempts to justify inductive reasoning in science, I have recently argued that a comprehensive treatment of induction requires moving away from viewing induction as an argument or inference— i.e., as a relationship involving statements or propositions. Therefore, I have advocated for a non-linguistic approach to induction to address these challenges (Barroso 2023, p. 265).

However, if induction is not argumentative or inferential—i.e., if it doesn't operate through statements—how does it function? This question needs to be addressed within the context of scientific practice. If explaining induction in science involves elucidating how scientific knowledge is validated, and if we acknowledge that this knowledge is acquired through experience, then it is crucial to depart from the linguistic treatment of induction, as it confines us to an a priori and syntactic analysis that relies on logical validity for justification.

In practice, scientists approach their subjects using models, such as iconic, mathematical, and scale models, etc., to interpret and represent the world, rather than relying solely on statements or propositions. Therefore, comprehending the nature of induction in science necessitates understanding this reasoning through the correlation between the events or phenomena in the world and their interpretations and representations, which essentially involves the notion of model in its semantic and pragmatic sense.

It has been said that induction has primarily been viewed through a linguistic lens, but this was not always the case. In the nineteenth century, William Whewell (1840ab) disputed the accounts of his contemporaries, Richard Whately and John Stuart Mill, who viewed induction as a form of argument or inference. Whewell argued that induction involved, on the one hand, the attribution of fundamental ideas and conceptions to objects and events in the world to connect them, and, on the other hand, the verification of these connections. Whewell called these processes of reasoning “discoverer's induction”.

5. William Whewell's induction: an interpretive and representative argument

It is noteworthy that Whewell's concept of induction differs radically from traditional accounts of induction. Firstly, rather than focusing on statements or propositions, Whewell's induction centers on conceptions and ideal cases. Secondly, instead of characterizing inductive reasoning as inferential reasoning, Whewell defines induction as the interpretation and representation of facts based on a fundamental idea or conception and an ideal case. Finally, he places the epistemic burden of justifying inductive beliefs not on a "supporting" relationship between the premises and the conclusion, but on the correspondence between the conceptions and the facts they reference.[5]

According to Whewell, the relationship that articulates the a priori dimension of knowledge with the empirical or a posteriori, is induction seen as an epistemological and methodological process that transcends mere observation of facts and presents them as interconnected. The outcome of this articulation is the introduction of a new element - a conception - superinduced in the facts but not derived solely from observing the facts themselves.

For example, the Greeks observed the movement of the planets through the analogy of a wheel within a wheel (1840b, p. 213), leading to the development of an interpretation to comprehend planetary motion using the conception of orbit. This mental creation was then amalgamated with the observed facts to represent them under the same conception, establishing the term 'orbit' as the reference for these observed movements. In this context, the conception of orbit serves as both an interpretation that enables us to perceive these events as a unified entity and a representation through which the phenomena were generalized.

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[5] In this regard, the work of Laura Snyder, who presents a reading of Whewell's philosophy that emphasizes the genuine character of his notion of induction and distinguishes it from other contemporary proposals (Snyder 1994; 1997; 2008; 2023), is very useful. See also the work of Corey Dethier (2018), who has suggested that Whewell's idiosyncratic notion of induction may be better understood in terms of a semantic framework of theories rather than a classical or enunciative one (Dethier 2018).

In another example, in physics, when we say that a body left to itself moves at a constant speed, we are not observing a body at rest; instead, we are portraying such a scenario as an "ideal case." An ideal case serves as a conceptual representation of a scenario that has not yet materialized or been fully interpreted—akin to perpetual motion. It is only by understanding the absence of perpetual motion (a key aspect of this ideal case) within the framework of the conception of "interacting forces" that we can make sense of it (1840b, p. 214).

Similarly, the representation - whether an 'ideal case' or a model - is formulated by scientists, while interpretation plays a crucial role in delineating the range of objects that fall under the purview of the theory. Consequently, according to Whewell, induction is viewed as a form of interpretive and representational reasoning, rather than an inferential one.

a. To induce is to interpret

Whewell posits that scientific progress primarily occurs through what he labels 'discoverer's induction.' This methodology encompasses the superinduction of an idea or conception and the colligation of empirical data. The superinduction of a conception involves mentally instantiating, consolidating the multitude of events or phenomena into a cohesive formulation, thereby uniting them (1840b, p. 36). Whewell explicitly draws parallels between the superinduction of a conception and the interpretative processes seen in semantics:

The process of mind of which we here speak can only be described by suggestion and comparison. One of the most common of such comparisons, especially since the time of Bacon, is that which speaks of induction as the interpretation of facts. Such an expression is appropriate; and it may easily be seen that it includes the circumstance which we are now noticing; -the superinduction of an idea upon the facts by the interpreting mind (1840b, p. 617).

From a semantic perspective, the process of superinducing a conception, which binds the facts together, can be viewed as delineating a structure that embodies or fulfills the underlying theory. Therefore, the superinduction of a conception can be interpreted as the process of constructing a model within a semantic context (1840b, p. 31).

The act of semantic interpretation, involving the superinduction of a conception and the correlation of events or phenomena, has often been overlooked by induction logicians. This trend traces back to the era of Aristotle, who defined induction as a form of reasoning that moves from one extreme term to another, establishing the truth of the middle term (1840b, p. 215). Consider the following inference: "Mars, Mercury, and Venus move in ellipses around the Sun," therefore, “All planets move in ellipses around the Sun.” By incorporating the premise "All planets exhibit the behavior of Mars, Mercury, and Venus," the argument transforms into a syllogism, hence a valid deduction. Nonetheless, as an empirical assertion, such a statement is not inherently obvious.

As Whewell noted, Aristotle and his followers focus on the evidence for the middle term, exemplified by the term 'ellipse' in the above example, over its invention. They prioritize form over substance and what is asserted over how it is asserted (1840b, pp. 215-216). On contrary, our analysis should examine how the superinduction of conceptions, such as that of an ellipse rather than an epicycle, effectively connects or interprets the objects we identify as planets in the solar system.

Whewell's approach to induction signifies an early acknowledgment of the semanticists' crucial intuition that the analysis of scientific theories transcends mere syntax. When scientists formulate a theory, they do not enumerate all the logical consequences of a theory's closed set of statements. Instead, they provide current or potential interpretations that correspond to how the theory is articulated. For instance, while Kepler's experiments were crafted to mathematically portray the orbits of Mars, he introduced the conception of ellipses -which was absent in Tycho Brahe's models- and postulated that the paths described by the planets were elliptical. His hypothesis encompassed not only the known planets (Mercury, Venus, Earth, Mars, Jupiter, and Saturn) but also undiscovered celestial bodies within the solar system, including Uranus and Neptune.

The previous example elucidates how inductive generalization is achievable from Whewell's viewpoint, or, in semantic terms, how one can interpret known and observed facts based on a conception that is unknown and unobserved. Whewell emphasized that,

In order to obtain our inference, we travel beyond the cases which we have before us; we consider them as mere exemplifications of some Ideal Case in which the relations are complete and intelligible. We take a Standard, and measure the facts by it; and this Standard is constructed by us, not offered by Nature (1840b, p. 214). [Italics ours].

By introducing an adequate conception, we establish an "ideal case," a representation in which the conditions under which events or phenomena are abstracted and idealized, can be interpreted. Subsequently, we regard the present cases as mere illustrations of this model or ideal case. Therefore, when we assert that φ states, "a body left to itself will move at a constant speed unless acted upon by an external force," it is not due to direct observation with our senses but rather because we treat φ as an ideal case, a model facilitating the comprehension of scenarios where bodies undergo changes or movements.

The conception, facilitated by the ideal case or model, introduces a level of universality that enables the connection and unification of facts. Let's consider a scenario where scientists unexpectedly discover a previously unseen planet in the solar system with a non-elliptical orbit. Does this discovery challenge the universality of the ellipse conception? No, as its universality pertains solely to planets with elliptical orbits. However, in terms of its alignment with the proposition to convey a connection, the scientific truth may exhibit some partiality in its expression as a hypothesis: not all planets in the solar system would fulfill the predicate of possessing an 'elliptical orbit,' but only specific ones that align with the ellipse conception.

Whewell posits that the universality offered by inductive reasoning lies not within the proposition itself but in the introduced conception: “Experience cannot lead to universal truths, except by means of a universal Idea supplied by the mind, and infused into the particular facts which observation ministers" (1847, p. 636).

From an epistemological perspective, induction, serving as a nuanced process of gathering data from a particular domain of knowledge, acts as the cognitive merging of objects and occurrences in the world. From a semantic viewpoint, induction establishes a correlation between our conceptions and specific facets of the world, ultimately imbuing meaning and structuring the complex array of phenomena. Whewell's notion of induction can be perceived as assigning interpretations to objects and events in the world.

For Whewell, logic serves as a framework for structuring reasoning based on a specific methodology. In deductive methodology, syllogism stands as the primary form, representing a type of argument that adheres to specific valid rules of inference. This form of reasoning upholds the truth of the premises within its conclusion, truths that preexist before the rules are applied. The form and rules of inference, devoid of empirical considerations, determine the argument's validity. Conversely, in Whewell's induction, the examination entails showcasing the circumstances under which the hypothesis may or may not hold true (1858, p. 98). Hence, the process of testing or validating hypotheses and theories is non-linear, characterized by an intricate network of confirmations rooted in evaluative reasoning.

b. …and also, to induce is to represent

The study of semantics is commonly identified as the domain concerning the meaning (or truth) of propositions, often seen as an extension to syntactic analysis—the epitome of logical reasoning par excellence. Within these deductive evaluations, the propositions constituting arguments lack empirical content; only their structure and, indirectly, their truth value are considered. While other factors related to sentence meaning—such as predicate structures, referenced events or objects, and contingency—exist, truth value remains the primary semantically significant aspect.

Issues such as the practical and cognitive processes involved in an individual's selection of specific systems to embody a given predicate, the influence of scientists and their communities in defining the meanings that underpin the truth of scientific statements, and related aspects, are frequently overlooked as they are deemed to transcend rational comprehension. Here, 'rational' refers to explanations based on logic or demonstrable inferences.

Traditional philosophers and logicians tend to prioritize form and truth-value assignment, often dismissing the pragmatic dimensions inherent in interpreting semantic concepts. Within the philosophy of science, crucial issues such as the criteria guiding scientists' acceptance of models, hypotheses, or theories; the influence of these criteria in defining scientific concepts and terms like definitions and classifications; and the deliberate composition of semantic elements within models represent pragmatic concerns that a narrowly semantic approach fails to capture. When referring to a "semantically narrow" stance, I address the limited scope of semantic analyses focusing solely on truth value assignment without exploring the processes leading to such truths. Essentially, semantics overlooks the pragmatic aspects contributing to the meaningful nature of scientific expressions.

The assertion that pragmatic aspects are fundamental to a philosophical analysis of science requires no further defense. The challenge lies in overcoming what Tarski identified as the 'malign reputation' of semantic concepts (Tarski 1956, p. 252). Specifically, this challenge entails reconciling the pragmatic dimensions of science with the development of rigorous and formal semantics that can cater to logical purposes. The crux of the matter is how to address the methodological issues of science, which are evidently pragmatic, through a semantic treatment that remains pertinent to logical syntax.

The acceptance of hypotheses or theories has been approached from both semantic and pragmatic perspectives in diverse manners (da Costa and French 1993; Suárez 1999, 2005; Cartwright 2006, 2012, 2013). Nevertheless, the relationship between evidence and the models, hypotheses, or theories remains inadequately elucidated. This transition between the semantic and pragmatic domains within science has been labeled as 'the semantic gap' by Helen Longino, highlighting the lack of alignment “between statements describing data and statements expressing hypotheses or theories to be confirmed or disconfirmed by that data." Originated by:

[T]he difference in descriptive terms used in the description of data and in the expression of hypotheses, means that evidential relations cannot be formally specified, and that data cannot support one theory or hypothesis to the exclusion of all alternatives. (Longino, 1990).

Supplementing Longino’s viewpoint, additional arguments—such as the underdetermination of theory by evidence and the inductive risk argument (cf. Brown 2013; Harvard and Winsberg 2022)—underscore the limitations of inductive reasoning inherent in conventional confirmation methodologies and, consequently, our experientially derived beliefs. These arguments illuminate the influence of values within scientific inquiry, particularly epistemic or constitutive values, which function as guiding criteria for scientists in bridging the aforementioned gap.

Values exert a fundamental influence on scientific practice, shaping decisions related to the acceptance of scientific models, hypotheses, or theories, and delineating the categorization of evidence, consequently enriching the contextual significance within scientific inquiry. Nevertheless, I question the idea that values being a solution to the uncertainties present in inferences and inductive reasoning within these practices.

In the field of science, the use of values is not just a mere solution but an intrinsic part of how science works. The challenges that arise are often not due to a semantic gap, but rather stem from a misinterpretation of the rationale that underpins the correlation between evidence and scientific models, hypotheses, or theories. These challenges arise from misinterpreting induction, considering it as a form of reasoning built on propositions or statements. This misinterpretation also touches upon the perceived lack of validity and rationality in empirical beliefs.

Whewell compares the verification process of a hypothesis or theory to the intricate bookkeeping practices of a multi-establishment enterprise handling substantial sums of finances managed by the central commercial office (1840b, p. 246). This analogy underscores the social and gradual nature of scientific inquiry. The verification process, akin to the intricate bookkeeping in large-scale commerce, does not hinge on the solitary endeavors of a lone scientist. Rather, it necessitates the collective contributions of multiple researchers investigating disparate elements across diverse geographical locations and temporal dimensions. As articulated by Whewell: "The statement is separated into certain comprehensive heads, and these into others less extensive; and these again into smaller collections of separate articles, each of which can be inquired into and reported on by separate persons." (1840b, p. 246).

Regarding the conditions of testing, determining whether a hypothesis is a scientific truth - meaning that the colligation is successful- requires verifying that its implications align with empirical evidence. This verification stems not only from careful and continuous observation of phenomena and the scientific depiction of the hypothesis's implications (Whewell, 1840b, p. 210) but also from ensuring that "certain cautions and conditions, of which we may hereafter speak, is held to be the evidence of its truth." (1840b, p. 211). The process of verification entails assessment based on defined criteria or conditions associated with epistemic or constitutive values, such as adequacy, prediction, consilience of inductions, and the tendency to simplicity.

In summary, according to Whewell, the acceptance of hypotheses or scientific theories entails specific practices centered on representations, known as representational practices. This involves two main aspects of representation: first, the act of inducing or superinducing a fundamental conception or idea onto facts, thereby establishing a cohesive bond that interprets them as a whole (1840b, p. 217). Secondly, representation involves presenting the conception as an ideal case, where certain aspects are abstracted or idealized to facilitate manageability for research purposes (1840b, p. 213). In contemporary terms, this ideal case is a representation or a model that scientists use to derive explanations, conduct explorations, make approximations, and fulfill other functions associated with models. Representation is a performative act that encompasses the induction of conceptions or ideas into facts, enabling the organization, grouping, or classification of originally diverse and unstructured elements of the world based on an ideal case or model, essentially, a representation.

6. Conclusions

The primary objective of this article has been to address contemporary calls for a paradigm shift in the traditional approach to induction, as highlighted by Norton (2005, 2014, 2021) and myself (Barroso 2023). This shift involves understanding induction as reasoning based on the semantic and pragmatic notions of model, rather than on statements or propositions. Additionally, it suggests that William Whewell's theory of induction provides a sound foundation for understanding inductive reasoning in this context.

Upon reviewing the traditional analysis of induction in the philosophy of science, it is evident that these approaches commonly suffer from being confined within a linguistic framework, as indicated by Hacking (1975). This framework is underpinned by a linguistic bias in the treatment of induction, portraying induction solely as argumentative or inferential reasoning (Barroso, 2023). Such an analysis is inadequate for various reasons, primarily because it represents induction in terms of statements, thereby limiting inductive reasoning to an analysis that necessitates formal correction, either consciously or subconsciously.

However, as demonstrated in this article, an examination of induction in significantly different terms is feasible. William Whewell's theory of induction enables us to account for the interpretive and representational processes involved in actual scientific practice. This encompasses the various types of reasoning and judgments utilized by scientists when constructing meaning and accepting hypotheses or theories.

In Whewell's induction, three processes are epistemically and methodologically relevant. First, the superinduction of an idea or conception, where facts are interpreted through a fundamental idea that gives them a bond of unity. Second, the colligation of facts, interpreting a series of observed facts under a new conception to classify them under the same commonality. Lastly, the verification process, testing the colligation through an ideal case or model.

The superinduction of an idea or conception, the colligation of facts, and the inductive process of verification can be understood from a contemporary perspective as model-based practices, which are interpretative and representational practices.

The construction of meaning in scientific practice occurs through model-based reasoning, which involves interpretations and representations. While the acceptance of a model, hypothesis, or theory is also a representational practice in which scientists necessarily use value judgments. Both aspects were anticipated in the philosophy of science by Whewell as part of inductive practices.

Whewell's concept of induction elucidates the functioning of certain model-based scientific reasoning methods, such as analogy, metaphor, idealization, and abstraction. Similarly, his criteria for evaluating models, hypotheses, or scientific theories encompass factors like adequacy, explanation, prediction, consilience of inductions, and simplicity. These criteria not only find widespread acceptance among contemporary scientists but also resonate with Whewell's vision of inductive reasoning. Whewell's perspective could offer a new way of approaching values in science.

In short, Whewell's induction provides elements for understanding the processes of interpretation and representation in science. The above justifies the validity of Whewell's induction as an adequate and rational reasoning, which underlies the plurality of methodologies present in scientific practice.

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References

Achinstein, P. (2010). The War on Induction: Whewell Takes on Newton and Mill (Norton Takes on Everyone). *Philosophy of Science*, *77*(5), 728-39.

Baker, S. F. (1957). *Induction and Hypothesis: A Study of The Logic of Confirmation*. Cornell University Press.

Bar-Hillel, Y. (1968). Inductive Logic as "the" Guide of Life. In Imre Lakatos (Ed.), *The Problem of Inductive Logic* (pp. 66-69). North Holland Pub.

Barroso, M. (2016). El falsacionismo popperiano: un intento inductivo de evadir la inducción. *Episteme, 36*(1), 29-40.

Barroso, M. (2023). A Framework for Inductive Reasoning in Model-Based Science. *Revista de Humanidades de Valparaíso*, 23, 259-285.

Bird, A. (1998). *Philosophy of Science*. McGill-Queen's Univ. Press.

Bird, A. (2005). Abductive Knowledge and Holmesian Inference. In Tamar Szabo Gendler y John

Hawthorne (Eds.), *Oxford Studies in Epistemology* (pp. 1-31). Oxford University Press.

Brown, M. J. (2013). Values in Science beyond Underdetermination and Inductive Risk. *Philosophy of Science*, *80*(5), 829-839.

Carnap, R. (1945). On Inductive Logic. *Philosophy of Science*, *12*(2), 72-97.

Carnap, R. (1947). On the Application of Inductive Logic. *Philosophy and Phenomenological Research*, *8*(1), 133-48.

Carnap, R. (1950). *Logical Foundations of Probability*. University of Chicago Press.

Carnap, R. (1952). Meaning Postulates. *Philosophical Studies, 3*(5), 65-73.

Carnap, R. (1966). The Aim of Inductive Logic. *Studies in Logic and the Foundations of Mathematics*, 44, 303-18.

Cartwright N. (2006). Well-Ordered Science: Evidence for Use. *Philosophy of Science*, *73*(5), 981-990.

Cartwright N. (2012). A theory of evidence for use. Canal: HT-fakulteterna vid Lunds universitet. https://www.youtube.com/watch?v=Fe-e0CyU-MA

Cartwright, N. (2013). Evidence, Argument and Prediction. *EPSA11 Perspectives and Foundational Problems in Philosophy of Science. The European Philosophy of Science Association Proceedings 2.* Springer https://doi.org/10.1007/978-3-319-01306-0_1

Da Costa, N. C. A. & French, S. (1993). Towards an Acceptable Theory of Acceptance: Partial Structures, Inconsistency and Correspondence. In S. French y H. Kamminga (Ed), Correspondence, Invariance and Heuristic (pp. 137-158). Kluwer Academic Publishers.

Da Costa, N. C. A. & French, S. (2003). *Science and partial truth: a unitary approach to models and scientific reasoning.* Oxford University Press.

Dethier, C. (2018). William Whewell's Semantic Account of Induction. *HOPOS: The Journal of the International Society for the History of Philosophy of Science*, *8*(1), 141–56.

Earman, J. (1992). *Bayes or Bust? A Critical Examination of Bayesian Confirmation Theory*. MIT Press.

Feigl, H. (1981). De Principiis Non Disputandum… ? On the Meaning and the Limits of Justification. In Robert S. Cohen (Ed.), *Inquiries and Provocations* (pp. 237-68). Springer Netherlands. https://doi.org/10.1007/978-94-010-9426-9_14.

Flach, Peter A., & Kakas A. (2000). Abductive and Inductive Reasoning: Background and Issues. In Peter A. Flach y Antonis C. Kakas (Eds.), Abduction and Induction (pp. 1-27). Springer Netherlands. https://doi.org/10.1007/978-94-017-0606-3_1.

Hacking, I. (1975). *The emergence of probability. A philosophical study of early ideas about probability, induction, and statistical inference*. Cambridge University Press.

Harman, Gilbert H. (1965). The Inference to the Best Explanation. *The Philosophical Review*, *74*(1), 88. https://doi.org/10.2307/2183532.

Harvard, S. & Winsberg, E. (2022). The Epistemic Risk in Representation. *Kennedy Institute of Ethics Journal,* 32 (1), 1–31.

Hempel, C. G. (1952). *Fundamentals of Concept Formation in Empirical Science.* University of Chicago Press.

Hempel, C. G. (1996). *La explicación científica. Estudios sobre la filosofía de la ciencia.* Paidós.

Hempel, C. G. (1965). *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*. The Free Press.

Hintikka, J. (1965). On a Combined System of Inductive Logic. *Acta philosophica Fennica, 22*(18), 21-30.

Hintikka, J. (1968). Induction by Enumeration and Induction by Elimination. *The Problem of Inductive Logic, Studies in Logic and the Foundations of Mathematics*, (51):191-231. https://doi.org/10.1016/S0049-237X(08)71045-0.

Josephson, J. R., y Josephson S. (1994). Conceptual analysis of abduction. In John R. Josephson y Susan G. Josephson Technology (Eds.), *Abductive Inference: Computation, Philosophy* (pp. 5-30). Cambridge University Press. https://doi.org/10.1017/CBO9780511530128.002.

Kelly, T. (2010). Hume, Norton, and Induction without Rules. *Philosophy of Science*, 77(5), 754-64. https://doi.org/10.1086/656548.

Kemeny, J. G. (1951). Carnap on Probability. *The Review of Metaphysics*, *5*(1), 145-156.

Kemeny, J. G. (1953). A Logical Measure Function. *Journal of Symbolic Logic*, *18*(4), 289-308. https://doi.org/10.2307/2266553.

Kemeny, J. G. (1955). Fair Bets and Inductive Probabilities. *Journal of Symbolic Logic*, *20*(3), 263-73. https://doi.org/10.2307/2268222.

Kemeny, J. G. (1963). Carnap's Theory of Probability and Induction. In Paul Arthur Schilpp (Ed.) *The Philosophy of Rudolf Carnap* (pp. 711-38). Open Court.

Lipton, Peter. (1991). *Inference to the Best Explanation*. Routledge y Kegan Paul.

Longino, H. (1990). *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry*. Princeton University Press.

Magnani, Lorenzo. (2001). *Abduction, Reason and Science.* Springer US. https://doi.org/10.1007/978-1-4419-8562-0.

Magnani, Lorenzo. (2007). Animal Abduction. In Lorenzo Magnani y Ping Li (Eds.), *Model-Based Reasoning in Science, Technology, and Medicine* (pp. 3-38). Springer. https://doi.org/10.1007/978-3-540-71986-1_1.

Magnani, Lorenzo. (2010). Mindless Abduction: From Animal Guesses to Artifactual Mediators. In M. Bergman, S. Paavola, A. Pietarinen, y H. Rydenfelt (Eds.), *Ideas in Action: Proceedings of the Applying Peirce Conference* (pp. 224-38). Nordic Studies in Pragmatism. Helsinki.

McCaskey, J. P. (2020). Reviving Material Theories of Induction. *Studies in History and Philosophy* *of Science Part A,* 83, 1-7. https://doi.org/10.1016/j.shpsa.2019.12.006.

Michalski, R. S. (1987). Concept learning. In S. Shapiro (Ed.), *Encyclopedia of Artificial Intelligence* (pp. 185-94). John Wiley.

Minnameier, Gerhard. (2017). Forms of Abduction and an Inferential Taxonomy. In Springer Handbook of Model-Based Science, Lorenzo Magnani & Tommaso Bertolotti (Eds.), (pp. 175-195). Springer International Publishing. https://doi.org/10.1007/978-3-319-30526-4_8.

Musgrave, A. (2012). Deductivism Surpassed: Or, Foxing in Its Margins? *Journal for General Philosophy of Science, 43*(1), 125-32.

Musgrave, A. (1999). How To Do Without Inductive Logic. *Science Education, 8*(4), 395-412. https://doi.org/10.1023/A:1008698208959.

Norton, J. D. (2003). A Material Theory of Induction. *Philosophy of Science, 70*(4), 647-70. https://doi.org/10.1086/378858.

Norton, J. D. (2005). A little survey of induction. In Peter Achinstein (Ed.), *Scientific Evidence: Philosophical Theories and Applications* (pp. 9-34), Johns Hopkins University Press.

Norton, J. D. (2014). A Material Dissolution of the Problem of Induction. *Synthese*, *91*(4), 671-90. https://doi.org/10.1007/s11229-013-0356-3.

Norton, J. D. (2021). *The material theory of induction*. University of Calgary Press.

Park, W. (2017). Magnani's Manipulative Abduction. In Lorenzo Magnani y Tommaso Bertolotti (Eds.), *Springer Handbook of Model-Based Science* (pp. 197-213). Springer International Publishing. https://doi.org/10.1007/978-3-319-30526-4_9.

Peirce, C.S. (1931). Collected Papers of Charles Sanders Peirce. In C. Hartshorne, P. Weiss, & A. W. Burks (Eds.). Harvard University Press.

Popper, K. R. (2002). *The Logic of Scientific Discovery*. Routledge.

Raisis, V. (1999). Expansion and Justification of Models: The Exemplary Case of Galileo Galilei. In Lorenzo Magnani, Nancy Nersessian & Paul Thagard (Eds.), *Model-Based Reasoning in Scientific Discovery* (pp. 149-164). Kluwer/Plenum.

Redhead, M. (1980). Models in Physics. *The British Journal for the Philosophy of Science*, *31*(2), 145-163.

Reichenbach, H. (1949). *The Theory of Probability: An Inquiry into the Logical and Mathematical Foundations of the Calculus of Probability*. University of California Press.

Reichenbach, Hans. (1957). *Experience and prediction: an analysis of the foundations and the structure of knowledge.* University of Notre Dame Press.

Russell, Bertrand. (2009). *Human knowledge: its scope and limits*. Routledge.

Salmon, W. C. (1963). On Vindicating Induction. *Philosophy of Science*, *30*(3), 252-61.

Salmon, W. C. (1965). The Concept of Inductive Evidence. *American Philosophical Quarterly*, *2*(4), 265-70.

Salmon, W. C. (1967). Carnap's Inductive Logic. *The Journal of Philosophy*, *64*(21), 725-39.

Snyder, L. J. (1997). The Mill-Whewell Debate: Much Ado about Induction. *Perspectives on Science*, *5*(2), 159-98. https://doi.org/10.1162/posc_a_00523.

Snyder, L. J. (1994). It's All Necessarily So: William Whewell on Scientific Truth. *Studies in History and Philosophy of Science*, 25, 785–807.

Snyder, L. J. (2008). 'The Whole Box of Tools': William Whewell and the Logic of Induction. In D. M. Gabbay & J. Woods (Eds.), *Handbook of the History of Logic* (pp. 163–228). North Holland: Elsevier.

Snyder, L. J. (2023). William Whewell, The Stanford Encyclopedia of Philosophy (Winter 2023 Edition), Edward N. Zalta y Uri Nodelman (Ed.). https://plato.stanford.edu/archives/win2023/entries/whewell/

Sober, E. (1988). *Reconstructing the Past: Parsimony, Evolution, and Inference.* MIT Press.

Sprenger, J. (2011). Hempel and the Paradoxes of Confirmation. In Dov M. Gabbay, Stephan Hartmann & John Woods (Eds.), *Handbook of the History of Logic* (pp. 235-63). North Holland. https://doi.org/10.1016/B978-0-444-52936-7.50007-0.

Suárez, M. (1999). Theories, Models, and Representations. In L. Magnani, N.J. Nersessian & P. Thagard (Eds.), *Model-Based Reasoning in Scientific Discovery*. Springer. https://doi.org/10.1007/978-1-4615-4813-3_5

Suárez, M. (2005). The Semantic View, Empirical Adequacy, and Application. *Crítica, Revista Hispanoamericana de Filosofía*, *37*(109), 29-63.

Sugden, R. (2009). Credible Worlds, Capacities and Mechanisms. *Erkenntnis*, *70*(1), 3-27. https://doi.org/10.1007/s10670-008-9134-x.

Tarski, A. (1956). The Concept of Truth in Formalized Languages. In J. H. Woodger (Ed.), *Logic, Semantics, Metamathematics. Papers from 1923 to 1938 by Alfred Tarski* (pp. 152-278). Hackett Publishing Company.

Urmson, J. O. (1974). Some questions concerning validity. In Richard Swinburne (Ed.), *The justification of induction* (pp. 74-84). Oxford University Press.

Van Fraassen, Bas C. (1989). *Laws and Symmetry.* Oxford University Press. https://doi.org/10.1093/0198248601.001.0001.

Watkins, J.W.N., (1992). A Neo-Popperian Advance on Popper? In Newton-Smith W.H. & Tianji Jiang (Eds.), *Popper in China* (pp. 138–157). Routledge.

Whately, Richard. (1827). *Elements of Logic*. J. Mawman.

Whewell, W. (1840a). *The Philosophy of the Inductive Science, Founded Upon Their History 1.* John W. Parker West Strand.

Whewell, W. (1840b). *The Philosophy of the Inductive Science, Founded Upon Their History 2.* John

W. Parker, West Strand.

Whewell, W. (1847). *The Philosophy of the Inductive Science, Founded Upon Their History, vol. 2.* John W. Parker, West Strand. https://play.google.com/books/reader?id=Ujg6AAAAMAAJ&pg=GBS.PP6

Whewell, W. (1858). *Novum Organon Renovatum. Third Edition.* John W. Parker West Strand. https://play.google.com/books/reader?id=9bUVAAAAYAAJ&pg=GBS.PP4

Williams, Donald. (1948). Induction and the Future. *Mind* LVII (226), 226-29. https://doi.org/10.1093/mind/LVII.226.226.

Worrall, John. (2010). For Universal Rules, Against Induction. *Philosophy of Science*, *77*(5), 740-53. https://doi.org/10.1086/656823.

Wright, G. H. (1965). *The Logical Problem of Induction*. Oxford Basil Blakcwell.