Studying Scientific Thought Experiments in Their Context: Albert Einstein and Electromagnetic Induction☆

Jan Potters[1]

Centre for Philosophical Psychology, Department of Philosophy, University of Antwerp

Bert Leuridan

Centre for Philosophical Psychology, University of Antwerp; Centre for Logic and Philosophy of Science, University of Ghent

---

Abstract

This article concerns the way in which philosophers study the epistemology of scientific thought experiments. Starting with a general overview of the main contemporary philosophical accounts, we will first argue that two implicit assumptions are present therein: first, that the epistemology of scientific thought experiments is solely concerned with factual knowledge of the world; and second, that philosophers should account for this in terms of the way in which individuals in general contemplate these thought experiments in thought. Our goal is to evaluate these assumptions and their implications using a particular case study: Albert Einstein's magnet-conductor thought experiment. We will argue that an analysis of this thought experiment based on these assumptions – as John Norton (1991) provides – is, in a sense, both misguided (the thought experiment *by itself* did not lead Einstein to factual knowledge of the world) and too narrow (to understand the thought experiment's epistemology, its historical context should also be taken into account explicitly). Based on this

---

☆The authors would like to thank Peter Verdée, John Norton, Tim de Mey, the audiences of the VAF (Rotterdam 2015) and CLMPS (Helsinki 2015) conferences, and a number of anonymous reviewers for their valuable and insightful questions, comments, and remarks.

Email address: `Jan.Potters@UAntwerpen.be` (Jan Potters)

[1] Corresponding Author, Research funded by the FWO (Research Foundation – Flanders)

Preprint submitted to Studies in History and Philosophy of Modern Physics *April 19, 2017*

evaluation we propose an alternative philosophical approach to the epistemology of scientific thought experiments which is more encompassing while preserving what is of value in the dominant view.

Keywords: scientific thought experiments, Albert Einstein, magnet-conductor thought experiment, argument analysis

1. Introduction

Since the publication of Ernst Mach's *Über Gedankenexperimente* (1897), many eminent philosophers of science such as Alexandre Koyré, Karl Popper and Thomas Kuhn have shown interest in scientific thought experiments (scientific TEs, or STEs, for short). In the contemporary philosophy of science the focus is mainly on their role in the epistemology of science. Our focus on these epistemological issues is of a more indirect nature. We are concerned primarily with the way in which contemporary philosophers of science conceptualize and study the epistemology of STEs: How do they try to answer such epistemological questions?[2]

We will proceed as follows. After a short sketch of the contemporary philosophical debate in section 2, we will argue in section 3 that there are two implicit assumptions about the epistemology of STEs underlying it. The case study in section 4 will then show how these assumptions can be problematic. John Norton's (1991) analysis of Einstein's magnet-conductor STE, which is based on these two assumptions is, in a sense, both misguided (the thought experiment *by itself* did not lead Einstein to factual knowledge of the world) and too narrow (to understand the thought experiment's epistemology, its historical context should also be taken into account explicitly). Based on this evaluation we propose an alternative philosophical approach to the epistemology of scientific thought experiments in section 5. This approach is more encompassing while preserving what is of value in the dominant view.

---

[2] This paper only concerns *scientific* thought experiments. It does not touch upon the issue of *philosophical* thought experiments.

2. The Philosophical Debate

2.1. James Robert Brown's Platonic Thought Experiments

For James Brown (1986; 1991a; 1991b; 2004; 2010; 2013), STEs are philosophically interesting because they deviate from the epistemological norm in science: while "the great bulk of our knowledge must be accounted for along empiricist lines, [...] there is [...] the odd bit that is *a priori* and it comes from thought experiments" (1991a, ix). What is epistemologically peculiar about them is the way in which they lead us to a new and better understanding of reality: we make an *a priori inferential leap* from the thought experimental data to new knowledge of the laws of nature[3]. This leap is special in two ways. First, it cannot be explained in terms of sensory experience, logical argument or theoretical simplicity (Brown, 1991b, 125 – 126). Second, it is very picturesque: the STE practically *shows* the truth of its conclusion to us (Brown, 2013, 57). This, for Brown, is why STEs form a special object of study for the epistemology of science.

To account for this, Brown draws an analogy with the epistemology of mathematics. The picturesque inferential leap experienced when one contemplates a STE is very similar, according to Brown, to how we gain mathematical insight. We acquire a priori knowledge of universal mathematical truths merely by looking at e.g. a 'picture' of a particular triangle (Brown, 1991b, 120). This can only be explained, he argues, by means of mathematical platonism (Brown, 1999): mathematical claims are true because there exist abstract mathematical objects, and we gain knowledge of them via our platonic intuition (Brown, 1991b, 121). The epistemology of STEs functions in a similar way. We gain a priori knowledge of the laws of nature merely by contemplating a particular picturesque scenario described in an STE. These laws of nature are true because of the existence of abstract objects: they are relations of necessitation holding between universals, in the sense of Dretske (1973), Tooley

---

[3] Brown calls STEs that produce such knowledge of nature 'platonic thought experiments' (Brown, 1991b, 124 – 125).

(1977) and Armstrong (1983). Our platonic intuition, which we need anyway to account for our mathematical knowledge, allows us to see these laws of nature, thus explaining our a priori knowledge acquisition when we contemplate particular STEs (Brown, 2004, 34).

2.2. John Norton's Argument View

Like Brown, John Norton is primarily interested in the epistemology of STEs. His aim is to explain how "[t]hought experiments are supposed to give us knowledge of the natural world" (2004b, 44)[4] or how "[t]hought experiments in physics provide or purport to provide us information about the physical world." (1991, 129)[5].

In contrast to Brown, however, Norton does not believe that STEs provide us with any *new* knowledge of nature: "[STEs] can only reorganize or generalize what we already know about the physical world and make it explicit" (Norton, 1996, 355). STEs, for Norton, are therefore *epistemically unremarkable* (1996, 334): they are nothing more than picturesque arguments (1996, 336) that lead us to knowledge of the natural world from premises consisting of "prior knowledge [which] rests eventually upon experience" (1996, 335). On this view successful STEs are, epistemically speaking, nothing more than deductive or inductive arguments, and this fully explains the "workings and achievements of any thought experiment" (Norton, 1996, 339). Norton summarizes his "eliminativist" and "reductionist" view on the epistemological functioning of STEs in the following two theses (see also 1991, 131):

(1) "All thought experiments can be reconstructed as arguments based on tacit or explicit assumptions. Belief in the outcome-conclusion of the thought experiment is justified only insofar as the reconstructed argument can justify the conclusion." (1996, 354)

(2) "The actual conduct of a thought experiment consists of the execution of an argument, although this may not be obvious since the argument may appear only in abbreviated form and with suppressed premises." (1996, 354)

---

[4] See also (2004a, 1139).

[5] See also (1996, 333).

Norton thus intends his argument-view to explain both how STEs establish and justify knowledge claims (in the context of justification), and how we actually conduct them (in the context of discovery). When we contemplate an STE, we are in fact following the underlying inductive or deductive argument that, if sound, brings us knowledge of the natural world (Norton, 2004b, 49). Norton argues for this argument-view by showing how different STEs from the actual history of science can be reduced to logical arguments, and by conjecturing that this is possible for all STEs (1996, 339). We will consider one of Norton's argument-reconstructions in more detail in section 4.2.

2.3. Tamar Szabo Gendler's Experiments-In-Thought

Like Brown and Norton, Tamar Szabo Gendler (1998; 2000; 2004) focuses on the epistemology of STEs (2004, 1152). For her, however, inferential approaches such as Brown's and Norton's cannot provide the full answer[6]. Philosophers should not only explain how STEs can bring about scientific knowledge, but also how they provide scientists with adequate evidence and justification for such scientific knowledge claims against opponents disputing these claims. This is what she describes as their *demonstrative force* (1998, 400). She argues for this by showing how Norton's analysis of Galileo's free fall STE can explain how it leads to a knowledge claim, but not why the original STE in itself provided scientists such as Galileo with evidence and justification for that knowledge claim in their debates with Aristotelians. This shows, according to Gendler, that such an argument-reconstruction is *evidentially weaker* than the original: while an Aristotelian had ways to reject the conclusion of the reconstructed argument, this was not the case for the original STE (Gendler, 1998).

---

[6] That Norton has an inferential account is clear: for him STEs are nothing more than logical arguments. Brown's account can be described as inferential as well: when we contemplate an STE's scenario, we make an *inferential* leap from the thought experimental data to the laws of nature. While this is not a formal derivation, Brown still compares it to some kind of inductive inference and natural kind reasoning (2010, 46).

On her analysis of Galileo's STE, inferential approaches fail because they reduce the picturesque form of STEs to an inference. For the STE to have demonstrative force in the dispute between Galileo and the Aristotelians, we have to take into account that contemplating it essentially involves making a picture of the situation described (1998, 411). More in particular, when we contemplate an STE, according to Gendler, we in fact perform an 'experiment-in-thought': by means of the general non-propositional pre-scientific intuitions about the functioning of reality that we are endowed with, we play the mental picturesque scenario and see what happens. In this way, Gendler claims to be able to account for both the epistemological and demonstrative significance of STEs: because of their picturesque form and the role of our intuitions in their contemplation, they are more convincing than a mere inference in disputes about scientific knowledge (1998, 414 – 415).

3. The Epistemology of Scientific Thought Experiments: Facts for Generic Individuals

The overview in the previous section shows that the accounts discussed all differ with respect to particular aspects of the epistemology of scientific TEs: Brown is concerned with how they bring about new a priori knowledge of reality; Norton, on the other hand, is interested in how they generalize and reorganize our knowledge of the natural world; Gendler, finally, focuses on their evidential significance in settling scientific disputes. At the same time, however, the overview also shows that all these philosophical accounts share the same conceptualization of what the epistemology of STEs should be concerned with. This conceptualization consists, we claim, of two specific assumptions. The first assumption concerns the epistemological issue that should be studied:

(Fac) **Factism**: Epistemological analyses of scientific TEs should explain how scientific TEs lead to *knowledge of the world*.

Brown, Norton and Gendler all assume that, epistemologically speaking, STEs bring scientists to some form of knowledge of the world,[7] and that this is what philosophers of science should explain. This assumption, in turn, goes together with a second, closely related methodological assumption about how philosophers of science should approach this epistemological issue:

(Ind) **Individualism** Philosophical explanations of the epistemology of scientific TEs should refer only to the way in which *individuals who contemplate scientific TEs in general* arrive at knowledge of the world in thought.

Brown believes that the epistemology of STEs should be explained in terms of the platonic inferential leap that we perform when going through an STE. Norton explains it in terms of the underlying argument that we are supposed to follow when we contemplate them. Gendler appeals to the way in which we perform experiments-in-thought. The following claims by Norton and by Brown give expression to (Ind) in a very concise manner: "[t]hought experiments are just what you thought" (Norton, 1996, 366) and "[t]hought experiments are performed in the laboratory of the mind" (Brown, 2010, 1).[8]

Philosophical accounts that study the epistemology of STEs in terms of these two assumptions ascribe to what we will call a (Fac)-(Ind) conceptualization of the epistemology of STEs. That there is such a conceptualization underlying the accounts of Brown, Norton, and Gendler is suggested by the overview above, as well as by the following remark by Gendler:

> That thought experiments can provide *us* with new *knowledge*[9] seems to be

---

[7] In the case of Norton and Gendler, the more specific term 'natural' world can be used. In the case of Brown it is not clear whether this would cover the platonic realm. Hence we use 'world' in the formulation of (Fac) and (Ind).

[8] For Norton, see also for example the introductory paragraph of his (2004a, 1139); for Gendler, see the conclusion of her (Gendler, 2004, 1162) article.

[9] Gendler is talking here about knowledge in the sense of justified true belief (2004, 1152).

> common ground among disputants in this symposium.[10] (2004, 1152 – 1153; emphasis added)

On this (Fac)-(Ind) conceptualization, STEs are epistemological objects of study in the sense that they bring whoever contemplates them in thought to knowledge of the world.

This conceptualization is not confined solely to the work of the three authors discussed above: many philosophical responses to their particular epistemological claims seem to take for granted at least some of its assumptions.[11] One problem is that these are never really argued for, nor are they really questioned: they mostly are implicit assumptions. We believe, moreover, that this conceptualization does not do complete justice to the epistemological role of thought experiments in science, a claim that we will make more precise in the next section by means of a particular case study, Einstein's magnet-conductor thought experiment. We thus intend this case to serve both as a way to evaluate the (Fac)-(Ind) conceptualization, and as a means to arrive at a more suitable conceptualization of what the epistemology of STEs should be concerned with, one that preserves what is of value in (Fac)-(Ind) while overcoming its shortcomings.[12]

---

[10] The symposium in question, which focussed on scientific thought experiments, took place at the 2002 Philosophy of Science Association (PSA) meeting. The participants were, among others, James Brown, James McAllister, John Norton, Nancy Nersessian and Tamar Szabo Gendler.

[11] The fact that we have only discussed three participants in the debate leaves open the possibility that our claim about the prevalence of the (Fac)-(Ind) conceptualization does not hold for the field in general. Still, the fact that most of the contemporary philosophical articles discussing the epistemology of STEs concern specific issues with these accounts. This seems to indicate that the field is at least heavily influenced by them. The following are only a selection of contemporary articles that raise issues with particular aspects of one of the three authors discussed in section 2, most of them more or less taking for granted at least one assumption about the epistemology of STEs: Richard Arthur (1999), Michael Bishop (1998; 1999), Alisa Bokulich (2001), Martin Bunzl (1996), Kristian Camilleri (2014; 2015), John Clement (2009), De Mey (2003; 2006), David C. Gooding (1992; 1994), Sören Häggqvist (2009), Ian Hacking (1992), James W. McAllister (1996; 2004) and Rafał Urbaniak (2012).

[12] One possible line of argument for (Fac), which participants in the debate may have used implicitly, was suggested to us by an anonymous reviewer. The implicit argument is this: Science makes progress. Thought experiments have played a central role in this. Therefore, thought experiments

(Before we proceed, we should nuance our claims in the previous paragraphs a little bit. We start from the observation that *de facto* there is a certain one-sided focus in the philosophical debate on the epistemology of scientific TEs. Doing so, we may well be guilty of an argumentative move which can be found all too often in the philosophical literature: to conclude from the fact that author A did never explicitly address topic T in writing (or never explored option O, or ...) that author A opposes to topic T (or opposes to option O, or ...). Such a conclusion need not follow. In fact, Norton has explicitly acknowledged[13] that he never intended the origin of factual knowledge to be the only epistemic issue associated with thought experiments. It just happened to be the most pressing and the one he wanted to address. However, we contend, in conjunction with the *de facto* one-sidedness described above this shows that there is room for a more encompassing approach.)

4. Case Study: Norton's Analysis of Einstein's Magnet-Conductor Thought Experiment

4.1. Einstein's Magnet-Conductor Thought Experiment

In the opening paragraphs of his special relativity article (1905), Albert Einstein presented what has become known in the philosophical literature as his magnet-conductor thought experiment. He presented it in the following words:

> It is well known that Maxwell's electrodynamics – as usually understood at present – when applied to moving bodies, leads to asymmetries that do not

---

have produced knowledge (in the sense of justified belief). We do not deny that many participants in the debate may have adopted this stance implicitly. Neither do we deny that it may help to substantiate the claim that some, or many, STEs have produced factual knowledge in the sense of (Fac). But it does not show that *all* STEs have contributed to the progress of science in this very way. We hope to show that Einstein's magnet-conductor experiment, which undoubtedly has contributed to the progress of fundamental physics, does not fit (Fac)-(Ind). We would like to thank the anonymous reviewer for pressing us on this issue.

[13] Personal communication.

seem to attach to the phenomena. Let us recall, for example, the electrodynamic interaction between a magnet and a conductor. The observable phenomenon depends here only on the relative motion of conductor and magnet, while according to the customary conception the two cases, in which, respectively, either the one or the other of the two bodies is the one in motion, are to be strictly differentiated from each other. For if the magnet is in motion and the conductor is at rest, there arises in the surroundings of the magnet an electric field endowed with a certain energy value that produces a current in the places where parts of the conductor are located. But if the magnet is at rest and the conductor is in motion, no electric field arises in the surroundings of the magnet, while in the conductor an electromotive force will arise, to which in itself there does not correspond any energy, but which, provided that the relative motion in the two cases considered is the same, gives rise to electrical currents that have the same magnitude and the same course as those produced by the electric forces in the first-mentioned case.

Examples of a similar kind, and the failure of attempts to detect a motion of the earth relative to the "light medium", lead to the conjecture that not only in mechanics, but in electrodynamics as well, the phenomena do not have any properties corresponding to the concept of absolute rest, but that in all coordinate systems in which the mechanical equations are valid, also the same electrodynamic and optical laws are valid, as has already been shown for quantities of the first order. We shall raise this conjecture (whose content will be called "the principle of relativity" hereafter) to the status of a postulate and shall introduce, in addition, the postulate, only seemingly incompatible with the former one, that in empty space light is always propagated with a definite velocity V which is independent of the state of motion of the emitting body. These two postulates suffice for arriving at a simple and consistent electrodynamics of moving bodies on the basis of Maxwell's theory for bodies at rest. The introduction of a "light ether" will prove superfluous, inasmuch as in accordance with the concept to be developed here, no "space at absolute rest" endowed with special properties will be introduced, nor will a velocity

> vector be assigned to a point of empty space at which electromagnetic processes are taking place.
>
> Like every other electrodynamics, the theory to be developed is based on the kinematics of the rigid body, since assertions of each and any theory concern the relations between rigid bodies (coordinate systems), clocks, and electromagnetic processes. Insufficient regard for this circumstance is at the root of the difficulties with which the electrodynamics of moving bodies must presently grapple. (Einstein, 1905, 140 – 141)

Einstein's STE starts with the claim that the phenomenon of electromagnetic induction provides an example of certain asymmetries that arise when "Maxwell's electrodynamics as usually understood at present" is applied to moving bodies. What Einstein refers to here is Lorentz's ether-based interpretation of this formalism, which at the time was generally considered to be the theory "that, of all existing electromagnetic theories, [...] best explained the extant data" (Miller, 1981, 131). Lorentz proposed his interpretation, at least partially, to account for the results of Michelson and Morley's ether-drift experiments, which aimed at determining experimentally the physical structure of the electromagnetic ether by measuring the effect of the earth's motion through the ether on the velocities of light waves[14]. The result, however, was a null-measurement: no effect of the earth's motion through the ether was detected (Nersessian, 1984, 107).

---

[14] At the time, the ether was considered to be both the medium carrying light waves and the absolute frame of reference for the laws of electromagnetism. These kinds of experiments attempted to establish the physical nature of the ether compared the velocity of a light wave travelling in the direction of the motion of the earth through the ether with the velocity of a light wave travelling perpendicular to the motion of the earth. If the earth was indeed moving through an ethereal substance, a particular difference should be measurable between the velocities of the different light-waves. The Michelson-Morley experiment was a very influential experiment of this kind, since the experimental apparatus used allowed for very precise measurements: the measurable effect could be as small as $10^{-8}v/c$. The precise difference measured would then allow them to decide between the two main, but incompatible, ether theories present at the time, i.e. one proposed originally by Jean-Augustin Fresnel and one by George Stokes. See e.g. (Darrigol, 2002, 316 – 319), (Stachel and Janssen, 2004, 15 – 20) or (Stachel, 2005, 3) for a thorough and technical explanation of the experiments.

Lorentz's proposed solution[15] was a completely immobile and unmoveable ether. The ether's immobility implied that it formed an absolute frame of reference for electromagnetic phenomena, thus imposing absolute velocities. As a consequence of the Michelson-Morley experiments, Lorentz's ether was also unmoveable: material bodies could not exert any direct force on the ether, nor vice versa (Stachel and Janssen, 2004, 22). Lorentz had to allow for some interaction between matter and ether, however, in order to account for the electrodynamics of moving bodies, i.e. those macroscopic phenomena involving moving dielectric and magnetic media (Miller, 1981, 143). This was done by his electron-theory. All material bodies consisted of electrons, minuscule particles with positive or negative charge. A body carrying an excess of one type of electrons was charged accordingly. These electrons gave rise to electric and magnetic fields as particular configurations of the ether. The ether could then indirectly act on matter via these fields exerting force on the electrons (Nersessian, 1984, 100 – 104; Jungnickel and McCormmach, 1990, 233; Darrigol, 2002, 357).

Within this setting, Einstein now presents the phenomenon of electromagnetic induction: the induction of an electric current in a conductor as a consequence of a magnet moving in its vicinity. Ether-based theories such as Lorentz's, Einstein points out, give rise to a distinction between two situations. In the first situation, we have a magnet moving with velocity $\mathbf{v}$ with respect to the ether past a conductor that is at absolute rest in the ether frame. At the location of the conductor in the ether, there is a time-varying magnetic field, which implies, following Faraday's induction law, that an electric field arises in the ether. By using the Lorentz force equation we can determine the electromotive force $\mathbf{F}$ exerted by the electric field on the electrons

---

[15] Lorentz had already shown in 1886 that Stokes' account relied on inconsistent assumptions, and he therefore considered Fresnel's approach as the only viable option. Fresnel's theory, however, was shown to be untenable by the Michelson-Morley experiments. At the time, however, nobody was willing to give up the electromagnetic ether, because the laws of electromagnetism, it was assumed, required an absolute frame of reference. Hence these experiments gave rise to a situation which indeed called for a solution (Nersessian, 1984, 105 – 109).

in the conductor, which gives us the direction and magnitude of the electric current in the conductor.

The second situation is exactly the opposite: a conductor moves with an absolute velocity $-\mathbf{v}$ with respect to the ether past a magnet at rest in the ether frame. Faraday's induction law then tells us that no electric field is present in the ether since the magnetic field in the ether frame does not vary in time. Again, we can use the Lorentz force equation to determine the direction and magnitude of the electric current.

It turns out, however, that the measurable magnitude and direction of the electric current will be exactly the same for both situations[16]. This, together with the failures of attempts to detect a motion of the earth with respect to the ether, leads Einstein to the conjecture ("*führen zu der Vermutung*") that "not only in mechanics, but in electrodynamics as well, the phenomena do not have any properties corresponding to the concept of absolute rest," and that "in all coordinate systems in which the mechanical equations are valid, also the same electrodynamic and optical laws are valid". Einstein then raises this conjecture ("*diese Vermutung*"), which he will call the principle of relativity from that moment, to the status of a postulate (Einstein, 1905, 140 – 141).

---

[16] For the precise derivation of this result, see the formal analyses of the STE in (Knudsen, 1980), (Miller, 1981) and (Norton, 2004c).

4.2. Norton's Argument-Analysis

In different articles (1991; 1996; 2004a; 2004b), John Norton[17] has claimed that, epistemologically speaking, STEs are in fact nothing more than "arguments which (i) posit hypothetical or counterfactual states of affairs, and (ii) invoke particulars irrelevant to the generality of the conclusions" (1991, 129). This is sufficient, in his view, to account for what he calls the epistemological problem of thought experiments in the sciences: "Thought experiments are supposed to give us knowledge. From where does this knowledge come?" (Norton, 1996, 333; Norton, 2004a, 1139): STEs are in fact deductive or inductive arguments that establish knowledge of the natural world by relying on premises that derive from experiment or experience, and when we contemplate such STEs we are brought to this knowledge because we are in fact following the underlying argument in thought. Norton's evidence for this philosophical account consists mostly of showing how different successful STEs from the history of science can all be reduced to such arguments. Norton's argument-reduction of the magnet-conductor STE, presented in (Norton, 1991), should thus be read as an example of, and as evidence for, Norton's general empiricist epistemology of STEs.

Norton begins his analysis of the magnet-conductor STE (1991, 135 – 136) by remarking that many of Einstein's STEs rely on a particular philosophical view on the relation between observation and scientific theories[18] (Norton, 1991, 135):

> *Verifiability heuristic for theory construction (version 2)*[19] States of affairs

---

[17] Important to note is that we are talking here about Norton's *philosophical* work on STEs, discussed in section 2.2: his argument view together with his elimination-thesis, which he has presented in (1991; 1996; 2004a; 2004b). We want to stress that we are not disputing Norton's more *historical* work on Einstein's theory of special relativity and the role of the STE therein, see e.g. his (2000; 2004c; 2010; 2013; 2014). We would also like to stress that our primary philosophical target is not Norton's argument-account *per se*, but rather the more general (Fac)-(Ind) conceptualization that, as we have argued in section 3, underlies the philosophical debate on the epistemology of STEs. We discuss Norton here primarily because he has discussed the magnet-conductor STE. Hence, Norton's analysis of Einstein's STE functions here *solely* as an *example* of a philosophical analysis of STEs in terms of the (Fac)-(Ind) concepualization identified earlier.

[18] This view, according to Norton, originated in the positivist rejection of any metaphysics and its prioritizing of observation over theoretical constructs.

[19] Norton starts by presenting a first formulation of the verifiability heuristic. He then proposes

which are not observationally distinct should not be distinguished by the theory.

As we have seen, the STE points out that ether-based interpretations of the laws of electromagnetism such as Lorentz's, when applied to the phenomenon of electromagnetic induction, give rise to a distinction between two different situations: one where an electric field is present, and one where no electric field is present. At the same time, as Norton points out, "as far as the observables are concerned – that is, the measurable current in the conductor – the two cases are indistinguishable" (Norton, 1991, 136). Given that the theory appeals to absolute velocities while the observables are only concerned with relative velocities, the verifiability heuristic tells us that electromagnetic theory should do away with absolute velocities for this particular phenomenon. An inductive argument referring to similar cases and to the failed attempts to detect the earth's motion through the ether then brings us to the STE's conclusion: "electrodynamics *should* seek to do without this absolute state of rest" (Norton, 1991, 136), which corresponds to the factual knowledge of the natural world that there is no absolute ether state of rest[20]. The following argument-reconstruction, quoted directly from (1991, 136), then explains, according to Norton, how Einstein arrived at this knowledge by contemplating the STE in thought:

1. In the case of electromagnetic induction, through its positing of an absolute state of rest, classical electrodynamics distinguishes states of affairs which are not observationally distinct.

   Therefore, in this case, classical electrodynamics violates
2. Verifiability heuristic for theory construction (version 2): therefore
3. Absolute velocities should be eliminated from the theoretical account of electromagnetic induction.

---

version 2 as an improvement and clarification of version 1, and claims that it was in fact version 2 that Einstein employed, albeit not always explicitly (Norton, 1991, 135).

[20] Professor John Norton phrased it in these latter terms in personal communication.

4. Inductive step: This example is typical since (a) there are other examples of this type, and (b) there is a history of unsuccessful attempts to detect this state of rest by optical experiments. Therefore
5. Absolute velocities should be eliminated from electrodynamics.

According to Norton's account, this inductive argument explains how Einstein's magnet-conductor STE brings us, in thought, to the knowledge of the natural world that there is no absolute ether state of rest: it shows how we get from premises that are rooted in experience (1) and experiment (4) to the conclusion (5) by following the steps in the argument. And, following Norton's reduction-claims (section 2.2), solely the inductive argument is responsible for this. Hence, Norton's analysis provides an example of what we have described as the (Fac)-(Ind) conceptualization of the epistemology of scientific TEs.

4.3. Assessing Norton's Analysis

In what follows we will point at some historical reasons that go against an analysis of the epistemology of the magnet-conductor STE in terms of (Fac) and (Ind), according to which the STE is supposed to bring those who contemplate it, Einstein as well as others, to the knowledge of the natural world that there is no absolute ether state of rest.

First, the way in which Einstein himself evaluated the STE's result. In his presentation of the STE, Einstein clearly states that the phenomenon of electromagnetic induction, together with the failed ether experiments, leads to the *conjecture* (*führen zu der Vermutung*) "that not only in mechanics, but in electrodynamics as well, the phenomena do not have any properties corresponding to the idea of absolute rest", and "that in all coordinate systems in which the mechanical equations are valid, also the same electrodynamic and optical laws are valid". He then raises this conjecture to the status of a postulate (*Wir wollen diese Vermutung [...] zur Voraussetzung erheben*), which, together with the constancy of the velocity of light postulate, will later enable him to attain a simple and consistent electrodynamics of moving bodies in which "a light ether will prove superfluous, inasmuch as in accordance with the concept to be developed here, no space at absolute rest endowed with special properties will be introduced" (Einstein, 1905, 140 – 141). The fact that Einstein speaks about conjectures and postulates indicates that he did not consider the results of this STE as factual knowledge.

Second, the way in which the scientific community at the time evaluated the STE's result. There are some good reasons to believe that for many physicists at the time the phenomenon of electromagnetic induction, in combination with the failure of the optical ether experiments, did not lead to the knowledge of the natural world that there is no absolute ether state of rest. As Arthur Miller, for example, has pointed out, the electromagnetic theories of Faraday, Maxwell, Hertz (who all wrote before the failed ether experiments) and Lorentz all agreed that only relative motion between the magnet and the conductor played a role in the induction of the current (Miller, 1981, 144). And Lorentz, in his *Versuch* (1895), had argued that the earth's motion through the ether, when considered as inertial motion, would have no observable influence on the phenomenon of electromagnetic induction (Miller, 1981, 144). This did not, however, bring Lorentz to the conclusion that there is no absolute ether state of rest. Moreover, as Olivier Darrigol has pointed out, most of the physicists who were aware of the asymmetry at the time of Einstein's publication did not see it as a reason for dismissing the electromagnetic ether:

> Among these authors [who had noted asymmetries in theoretical representations of the induction phenomenon], Preston was the only one who wished to eliminate the theoretical asymmetry. Heaviside and Föppl believed that the source of the asymmetry, the ether or absolute space, really existed, and that other electrodynamic phenomena, or finer details of the induction phenomenon, would depend on absolute motion. Wien's and Lorentz's only concern was that the asymmetries should have no undesired experimental consequences. The pertinent question is not how Einstein became aware of asymmetries without empirical counterpart, but what made them so intolerable to him. (Darrigol, 2006, 378)

This shows that many scientists at the time did not take the phenomenon of electromagnetic induction, even in combination with the failed optical ether experiments, to lead to the factual knowledge that there is no absolute ether state of rest.[21] We would like to stress here that we do not claim that the magnet-conductor STE does not concern the natural world at all[22]. What the above indicates, however, is that analyzing the STE in (Fac)-(Ind) terms is misguided: it is not the case that the magnet-conductor STE *in itself* brought Einstein, or other physicists, to the factual knowledge of the natural world that there is no absolute ether state of rest. This, of course, then raises the question how we should understand the results of the STE, epistemologically speaking: what does it mean that Einstein claims that the STE brings him to his conjecture – later to be raised to a postulate (1905, 140 – 141)? As we will indicate in the next section (4.4), to answer this question we need to situate the STE in the historical context in which it was presented by Einstein. This will then lead us, in section 5, to propose a conceptualization of the epistemology of scientific TEs that can capture the epistemological role played by the magnet-conductor STE, while preserving what is of value in (Fac)-(Ind).

4.4. Returning to the Magnet-Conductor Thought Experiment

The phenomenon of electromagnetic induction was first studied by Michael Faraday, who captured it in his induction law: in the presence of a time varying magnetic field, an electromotive force arises in a closed conductor. According to Miller, the STE's asymmetry indicated to Einstein that Faraday's law was being misinterpreted (1981, 144). This can be explicated as follows:

> Einstein is careful to avoid claiming that an equation leads to asymmetry (or symmetry) in the phenomena because that would be an improper mixture of categories. Strictly speaking, equations do not lead to phenomena; rather, they

---

[21] See the second part of Stanley Goldberg's (1984) book, chapters 6 – 10 from Richard Staley's (2008) book, or the edited volume by Thomas Glick (1987) for some overviews of the way in which the special theory of relativity was received.

[22] We would like to thank an anonymous referee for pressing us on this issue.

> lead to mathematical descriptions of phenomena which, in turn, can be interpreted physically – this is the theory – as exhibiting (a)symmetrical features. In this way the theory (not the equations by themselves) can lead to asymmetry (or symmetry) that does not correspond to anything in the phenomena. Thus, the asymmetry is an "artifact" of the theory; it does not "adhere" to the phenomena. (Hon and Goldstein, 2005, 481)

Faraday's induction law provides us with a mathematical equation ($\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$), which can then be employed to formulate a mathematical description of the phenomenon of electromagnetic induction, in which the motion of a magnet and a conductor with a particular velocity $\mathbf{v}$ gives rise to a particular electromotive force $\mathbf{F}$ in the conductor. Theory then, in turn, gives a physical interpretation to this mathematical description: it tells us how we should understand the elements that figure in the description[23].

When the action between the conductor and the magnet is interpreted in terms of the ether, as the physical carrier of electric and magnetic fields and as the absolute frame of reference for the laws of electromagnetism, Einstein's asymmetry plays up: "the theory [...] distinguishes different cases based on the choice of which body is moving and which is at rest, whereas only the relative motion is relevant" (Hon and Goldstein, 2005, 481). For Einstein, however, the STE's fundamental issue was not primarily with the electromagnetic ether as such. Rather, as Miller has pointed out, Einstein's concern was with a more general tension between mechanics and electromagnetism: "[c]onsidering the case of electromagnetic induction within the

---

[23] According to Faraday, for example, the magnetic field $\mathbf{B}$ was made up of magnetic field lines rigidly connected to the magnet. On this interpretation, the induction law then stated that "the total electromotive force in a conductor is proportional to the number of magnetic field lines moving across the conductor in unit time" (Knudsen, 1980, 347 – 348). Knudsen (1980) gives an extensive overview of the different interpretations of Faraday's induction law throughout the nineteenth century, and Giora Hon and Bernard Goldstein (2005) have elaborated on this. Both have pointed out that Faraday's own interpretation did not lead to Einstein's asymmetry (Knudsen, 1980, 349; Hon and Goldstein, 2005, 480). Nancy Nersessian (1984, 37 – 68) provides an in-depth treatment of Faraday's interpretation of the magnetic field in terms of magnetic field lines.

context of a theory of principle [. . .] enabled Einstein to cut directly to the heart of a basic problem of current science and technology – the tension or incompatibility of mechanics and electromagnetism" (Miller, 1981, 164). This tension concerned the fact that the laws of mechanics were subject to the principle of Galilean relativity, while electrodynamics required an absolute frame of reference in order to account for the constant velocity of light[24].

At the time, the most common attempts to overcome this problem involved reducing either mechanics to electrodynamics or vice versa. Mechanical approaches, such as those by e.g. Hertz or Boltzmann (Miller, 1981, 126 – 127), took Newton's laws, with the principle of relativity, to be the fundamental laws of nature: hence they interpreted all physical phenomena as cases of material objects in motion. The electromagnetic approach on the other hand, with proponents such as Wien and Abraham (Miller, 1981, 131), took Maxwell's laws as the fundamental principles governing nature: they therefore conceived of all physical phenomena in terms of fields as states of the ether (Wolters, 2012, 40 – 41).

Einstein had several reasons to discuss the tension between electromagnetism and mechanics within the framework of Lorentz's theory. First, as Miller points out, it was "the current opinion that, of all existing electromagnetic theories, Lorentz's best explained the extant data" (Miller, 1981, 131), and Einstein agreed with this. Moreover, Lorentz's theory was considered by some to offer one of the most promising approaches to formulating an electromagnetic foundation for physics[25], albeit not

---

[24] These were considered to be incompatible as follows. Since Maxwell, it was generally accepted that all electromagnetic phenomena propagate at the speed of light, which was known at the time to have a constant, finite velocity, independent of the velocity of the source. Within the framework of Galilean relativity, this required an absolute frame of reference for all electromagnetic phenomena: if not, the velocity additivity principle – which states that the velocity v of an object in an inertial frame F moving at a velocity v' with respect to another inertial frame F' is $v + v'$ in F' – would allow for the possibility of light waves travelling with a velocity $c + v$ in a particular frame of reference, thus contradicting light's constant velocity. In this way the constancy of the velocity of light together with Galilean relativity and the velocity additivity principle were thus incompatible with the principle of relativity (Angel, 1980, 62 – 63; Ferraro, 2007, 47; Rynasiewicz, 1998, 163).

[25] As an approach to formulating an electromagnetic view of nature, Lorentz's theory was primarily popular with other proponents of the electromagnetic view, such as e.g. Abraham. Lorentz

without problems (Miller, 1981, 75 – 86; Darrigol, 1996, 277). A final reason was that Lorentz's theory, for Einstein, embodied what was responsible for the 'incompatible tension' between mechanics and electromagnetism. As we have seen in section 4.1, Lorentz attempted to resolve the incompatibility between mechanics and electromagnetism by postulating two fundamental entities, i.e. the ether and his electrons, between which there was no direct interaction possible. As Miller puts it, Einstein was struck by this dualism: "Why should both particle and field be considered as elementary?" (1981, 131).

At the time, most proposed solutions to the tension between mechanics and electromagnetism started with a particular set of models – either mechanical models in terms of material objects in motion governed by Newton's laws or electrodynamical models formulated in terms of fields in the ether obeying Maxwell's equations – which they assumed to be sufficient to explain all features of the physical world.[26]

According to Einstein, however, such approaches could not prove fruitful here, since they did not address what was actually responsible for the tension. Proponents of both the mechanical and the electromagnetic approach assumed that only one of the two principles – relativity or constant velocity of light – could be fundamental, and that, because of their incompatibility, the other had to be reduced. According to Einstein, however, the two principles were only "seemingly incompatible", as he stated after his presentation of the magnet-conductor STE (1905). What was re-

---

himself did not fully commit to an all-encompassing electromagnetic view of nature (Darrigol, 1996, 278).

[26] The way in which Einstein's special theory of relativity differs from e.g. the electromagnetic and mechanical view of nature is often expressed in terms of Einstein's own distinction between theories of principle and constructive theories, which he formulated in (1919). In Miller's (1981) account of the emergence of the special theory of relativity, for example, it plays a central role. There are, however, some historical difficulties with analysing the epistemology of Einstein's STE (1905) in terms of an epistemological distinction that Einstein formulated in (1919). For one, there is no way to exclude the possibility that his epistemological interpretation (in 1919) of the special theory of relativity was influenced by its later success, or by some of his other scientific endeavors. We have therefore decided not to put too much emphasis on this distinction here. (We would like to thank an anonymous referee for pressing us on this issue.)

sponsible for the tension, according to Einstein, was not the incompatibility of the two principles themselves, but rather the distinct transformation rules that they employed. These were the principles that ensured that their respective laws, Newton's laws and Maxwell's equations, were the same from different viewpoints, i.e. between different frames of reference: the Galilean transformations for the laws of mechanics, and Lorentz's transformations for the laws of electrodynamics[27]. These transformations relied on different, and incompatible, notions of time and simultaneity, and this is what Einstein took to be the real cause of the tension:

> [T]he mathematical statement of the "principle of relativity" from mechanics (the Galilean transformations) did not leave unchanged the equations of Lorentz's electrodynamics. [...] Lorentz's modified Galilean transformations did not leave unchanged the laws of mechanics. [...] [T]he transformation rules for the laws of mechanics and of electromagnetism depended upon two different notions of time, one physical the other mathematical, despite Lorentz's goal of unification. Thus whereas current physics considered a tension to exist between mechanics and electromagnetism that was rooted in the inability of mechanics to describe the velocity of light, Einstein delved deeper and found that current physics rendered mechanics and electromagnetism incompatible. (Miller, 1981, 189)

According to Einstein, neither mechanical nor electromagnetic attempts could prove fruitful here, since their transformation principles inherently relied on different, incompatible notions of time and of the simultaneity of distinct events in particular[28]. What was needed to overcome the tension, rather, was a reconceptualization of these notions that fitted both principles that were in fact only "apparently incompatible". This reconceptualization could then in turn be employed to construct a theory for

---

[27] Stachel and Janssen (2004) provide a good and extensive account of how the tension between these two principles played out in physics at the time.

[28] Miller (1981, 123 – 137) provides an extensive overview of Einstein's problems with both the mechanical and the electromagnetic approach.

the electrodynamics of moving bodies that obeyed both principles and made use of the same transformations[29]. It is in this way that the special theory of relativity proposes to overcome the tension between mechanics and electromagnetism in such a way that "the introduction of a light ether will prove to be superfluous": the two postulated principles constrain the formulation of the kinematics that is to be employed in the interpretation of the laws of electromagnetism, which results in an electrodynamics of moving bodies that obeys both the principle of relativity and the postulated constancy of the velocity of light. (Stachel, 2002, 164 – 165).

So how should we understand the role that the magnet-conductor STE played in this dismissal of the light ether, if it does not concern knowledge of the natural world? In a manuscript from 1920, Einstein himself described the STE's effect as follows:

> The idea . . . that these were two, in principle different cases was unbearable for me. The difference between the two, I was convinced, could only be a difference in choice of standpoint and not a real difference. Judged from the magnet, there was certainly no electric field present. Judged from the electric circuit, there certainly was one present. Thus the existence of the electric field was a relative one, according to the state of motion of the coordinate system used, and only the electric and magnetic field together could be ascribed a kind of objective reality, apart from the state of motion of the observer or the coordinate system. The phenomenon of magneto-electric induction compelled me to postulate the (special) principle of relativity. [Footnote by Einstein:] The difficulty that had to be overcome was in the constancy of the velocity of light in a vacuum which I had first thought I would have to give up. Only after groping for years did I notice that the difficulty rests on the arbitrariness of the kinematical fundamental concepts. (Miller, 1981, 145)

---

[29] Einstein proposed such a radically new interpretation of the concepts of simultaneity, space and time, in section I of his (1905) article, right after his presentation of the STE, and right before he proposed a reformulated kinematics (part I) and electrodynamics (part II). (Angel, 1980, 63 – 81), (Miller, 1981, 185 – 206), (DiSalle, 2006, 98– 111), (Darrigol, 2006, 20 – 26) and (Ferraro, 2007, 47 – 95) all offer thorough and technical overviews of Einstein's proposal.

The STE suggested, according to Einstein, that to overcome the asymmetry, the difference between the two situations – electromagnetic induction with and without electric field – should reflect merely a difference in viewpoint and not a real difference: while an observer in the rest-frame of the conductor would then describe the phenomenon in terms of an electric field, an observer in the rest-frame of the magnet would describe it without. In general, however, it would only make sense to speak about the electromagnetic field as a whole. This is what Einstein means with the electric field's relative existence: "the distinction between an electric field and a magnetic field in the case of moving bodies is meaningless; there is only an electromagnetic field which may be perceived differently by different observers" (Hon and Goldstein, 2005, 483).

Epistemologically speaking, the magnet-conductor STE puts Einstein on the way towards a covariant interpretation of the laws of electrodynamics, i.e. one that makes them come out true in every inertial frame of reference.[30] Such an interpretation would allow him to overcome the asymmetry pointed out in the STE. More in particular, we claim, the STE contributes to this both on a methodological and on an ontological level, without reaching decisive outcomes at either level *in itself*.

The methodological level concerns the practice of formulating such an interpretation. As we have indicated earlier – see the quote by Darrigol on page 17 –, most physicists at the time did not take the asymmetry to argue against ether-based interpretations of the laws of electromagnetism. Einstein was dissatisfied with approaches that attempted to reduce the whole of physics to one kind of model, be it mechan-

---

[30] Making the laws of electrodynamics covariant means devising a procedure that enables us to transform the laws of electrodynamics from one inertial frame of reference to another while making them come out true in every frame. Here this comes down to the following. The phenomenon of electromagnetic induction can be described both with and without an electric field, depending on the frame of reference of the observer. For both observers, however, the Maxwell equations should say exactly the same: the direction and magnitude of the current should be equal. The transformation principles should ensure this: they should provide us with a principled way to keep the laws of electrodynamics come out true when transforming from one inertial frame where electromagnetic induction is described with an electric field to an inertial frame where it is described without.

ical or electromagnetic, and he believed that progress could be made primarily by focussing on the principles that are to constrain the construction of theories and models for particular phenomena. Now, as Arthur Miller has pointed out, "electromagnetic induction involved both mechanics and electromagnetism" (1981, 163): the induction of an electric current in the conductor is a consequence purely of the relative motion of the magnet and the conductor. Within the context of Einstein's focus on constraining principles, the STE then suggests to Einstein that electromagnetic phenomena such as electromagnetic induction obey both the principle of the constancy of the velocity of light as well as the principle of relativity. The STE thus provides him with the principles that are to constrain the formulation of his interpretation of the laws of electromagnetism. This in itself, however, is not yet sufficient to arrive at an approach that can overcome the asymmetry: as Einstein himself points out – see the quotes both on page 9 and on page 23 –, a renewed attention for the kinematics that is to be employed in formulating a relativistic covariant interpretation of the laws of electromagnetism is also required. This is why the asymmetry only gets resolved in part II, §6 of Einstein's (1905) article (Rynasiewicz, 1998, 160 – 163). Hence, the STE forms *part of* Einstein's attempt to shift the methodology employed in the foundations of physics.

The ontological level concerns what such an interpretation tells us that there is. As we have indicated earlier, the STE brought Einstein to the relative existence of the electric field: see the quote on page 23. More in particular, as John Norton himself has argued, the STE brought Einstein to the principle for transforming the electric field from one inertial frame to another: $\mathbf{E} = \mathbf{E}' + (1/c)(\mathbf{v} \times \mathbf{H}')$ (Norton, 2004c, 51).[31] This counts as an ontological contribution, since the special theory

---

[31] In short, the STE accomplishes this as follows. If, following the principle of relativity, we take both situations in the STE to be descriptions of the same phenomenon from different inertial frames of reference, then we notice that the electric field changes from $\mathbf{E} = 0$ in the rest-frame of the magnet to $\mathbf{E}' = \mathbf{E} + (1/c)(\mathbf{v} \times \mathbf{H}')$ in the rest-frame of the conductor. Important to note, however, is that the STE itself does not provide the full set of frame transformations, as Norton himself also stresses: "it is unlikely that Einstein inferred directly to the [complete] first order Lorentz transformations from the magnet and conductor thought experiment" (2004c, 52). This is

of relativity was the first to introduce symmetries and covariant transformations as criteria for assessing objective existence within physical theories(DiSalle, 2009; Kosso, 2003; Martin, 2003).[32] Again, however, this suggestion in itself is not sufficient to overcome the asymmetry, since the same formal principles were employed by Lorentz to transform problems in electrodynamics to an absolute rest frame, the ether (Miller, 1981, 34). What is needed to overcome the asymmetry, in addition to these covariant transformations, is, again, Einstein's kinematics with its reconceptualization of time. Hence, the STE forms *part of* Einstein's attempt to shift the objects studied in the foundations of physics (i.e. those characteristics that are covariant under the transformation procedures).

Summing up, the STE was *part of* Einstein's attempt to shift the standards of scientific epistemology for fundamental physics towards a new methodology for interpreting the laws of physics and towards a new ontology of science. The new ontological interpretation has it that the objective characteristics with which physical theories should be concerned are those that are covariant under the relativistic transformation procedures. The new methodology says that the formulation of such theories should be constrained by both the principle of relativity and the light postulate, where those are only compatible when we make use of Einstein's conception of simultaneity. The magnet-conductor STE participated in this shift by suggesting both the principles that are to constrain Einstein's interpretation of the laws of electrodynamics and the covariant transformation principle for the electric field. In themselves, however, these suggestions do not prove that the light ether is superfluous; hence they do not lead to the factual knowledge that there is no absolute ether state of rest.

---

so because the magnetic field does not differ between the two situations: $\mathbf{B} = \mathbf{B}'$. Hence the same reasoning as for the electric field does not apply: we cannot infer the magnetic field's transformation rule $\mathbf{B} = \mathbf{B}' - (1/c)(\mathbf{v} \times \mathbf{E}')$ directly from the magnet-conductor STE (Norton, 2004c, 52).

[32] We would like to thank a referee for pressing us on this issue.

5. An Alternative Proposal: Thought Experiments Transforming Context

In sections 2 and 3 we pointed out that the contemporary philosophical debate on the epistemological role of STEs studied them in terms of a particular conceptualization, which we characterized as (Fac)-(Ind). In section 4, we discussed John Norton's analysis of Einstein's magnet-conductor STE as an example of a philosophical analysis based on this conceptualization. We pointed out that there were historical reasons to doubt Norton's (Fac)-(Ind) claim that the magnet-conductor STE brought Einstein, or other scientists for that matter, to the knowledge of the natural world that there is no absolute ether state of rest. We then returned to Einstein's STE in order to clarify its epistemological role. This revealed that the STE played an important part in Einstein's attempt to shift the epistemological standards of fundamental physics at the time, by suggesting ways to reconceive both its methodology and its ontology. At the same time, however, we also pointed out that the STE did not accomplish this by itself. Other elements of Einstein's paper (1905), such as his reconceptualization of simultaneity, also played an important role. Moreover, as e.g. Michel Janssen points out, even Einstein's article as a whole was only part of this shift: "Einstein's introduction of the special theory of relativity in 1905 is best understood as one of the catalysts of a much broader revolution in early twentieth-century physics" (Janssen, 2002a, 431). Our aim in this section is to clarify what we take to be some of the general lessons for the epistemology of STEs.

Philosophical accounts relying on (Fac) assume that STEs lead to knowledge of the world, but Einstein's magnet-conductor experiment runs counter to this assumption. It did not lead to the factual knowledge that there is no absolute ether state of rest. Instead it was part of a broader epistemological transformation of the way in which physicists should interpret the laws of physics (both on a methodological and on an ontological level). In order to account for this, we propose the following metaphilosophical assumption as an alternative to (Fac):

(Tra) **Transformationism**: Epistemological analyses of scientific TEs should account for the role scientific TEs play in the transformation of their epistemological context.

The most important difference with (Fac) is that (Tra) is less restrictive with respect to a STE's epistemological result. Unlike (Fac) it does not assume that this always concerns knowledge of the world. Hence (Tra) does not clash with the epistemological role of the magnet-conductor STE.

(Tra) does not dispute that particular STEs *can* bring about knowledge, but it does not require it either. There are other kinds of epistemic transformations as well that can occur because of a STE besides bringing about knowledge. In this way we hope to accomplish the central purpose of this article: to argue against the assumption (Fac) that the epistemology of STEs *merely* concerns knowledge of the world. The epistemological role of STEs can be broader than that.

Proposing (Tra) as an alternative to (Fac) also brings us to shift our focus from the individual contemplating the STE in thought (Ind) to its broader scientific *context*. Hence we propose to replace (Ind) with another, more encompassing metaphilosophical assumption:

(Con) **Contextualism**: Philosophical accounts of the epistemology of scientific TEs should refer to the way in which scientific TEs bring about changes within the relevant scientific context, where this context is constituted by the historical elements involved in the formulation, presentation and reception of the STE.

The most important difference with (Ind) is that (Con) does not assume that the epistemological transformations brought about by the STE — be they the establishment of knowledge, the shifting of epistemological standards or still something else — should be explained solely in terms of generic individuals contemplating the STE in thought. Rather, (Con) refers to the broader historical and scientific context in which the STE was formulated, presented and received, and it urges us to be explicit about the elements of the scientific context that played a role in the transformation brought about by the STE. Such a contextualization of the STE's epistemological result is needed in order to account for the fact – see page 17 – that different scientists drew different conclusions from the fact that ether-based theoretical descriptions of electromagnetic phenomena gave rise to asymmetries of the kind pointed out by Einstein.

We would like to stress here that we do not claim that philosophers working within a (Fac)-(Ind)-conceptualization are wholly oblivious to, or unconcerned with, the theoretical and social context of STEs. In fact, Norton repeatedly endorses the role of, and influence on, contextual features in his historical work. But we argue against the (Ind)-assumption that, with respect to the *epistemology* of STEs, only the individual contemplating the STE is what counts. Recall Norton's slogan that STEs are just what you thought (1996, 366) or Brown's claim that they are performed in the laboratory of the mind (2010, 1).[33]

(Con)-(Tra) leads to the following analysis of the magnet-conductor in terms of the transformations that occured in the context of the debates on the foundations of physics, due to its formulation, presentation and reception:

A first change that we have observed was the derivation of the transformation rule for the electric field, which can be accounted for in terms of a formal derivation within the framework of Lorentz's electrodynamics, as John Norton has done in one of his historical articles on Einstein's special relativity (2004c). We thus have our first historical constituent of the STE's context: the Maxwell-Lorentz theory of electromagnetism.

A second change that we have observed in section 4.4 was Einstein's focus on principles that should constrain the interpretation of the laws of physics, which brought him to postulate the principle of relativity and the light postulate. We can account for this in terms of his views on the debate between the electromagnetic and the mechanical approaches, and his views on the formulation and evaluation of scientific theories. These provide us with the second constituent of the magnet-conductor STE's context: the individual scientist Albert Einstein.

A third change concerns the way in which the scientific community at the time

---

[33] We would like to thank an anonymous referee for pressing us on this issue.

reacted to the STE within the framework of special relativity. We have not discussed this in much detail, but Stanley Goldberg (1984, 179 – 320) has provided an extensive overview of the way in which scientists in Germany, France, the United Kingdom and the United States responded to the general conclusions of special relativity between 1905 and 1911.[34] According to Goldberg, the initial scientific reaction to special relativity in fact consisted of what he describes as "national styles" (Goldberg, 1984, xiv): the reaction in Germany differed e.g. strongly from the reaction in France or in the United States, differences which Goldberg accounts for by referring e.g. to the kind of education that scientists enjoyed in these respective countries or to the leading scientific figures in these countries at the time.[35] This then provides us with a third constituent of the STE's context: the debates in the fundamental physics-community at the time of Einstein's publication.

This historical context allows us to account for the epistemological transformation that occured because of the STE. More in particular, taking the historical context to consist of multiple elements undergoing change allows us both to explain how the STE suggested to Einstein that an interpretation of the laws of electromagnetism without the ether was possible, and to explain why the reaction in the community at the time were very diverse. For example, the fact that the STE had a different epistemological effect on Einstein compared to Lorentz can be accounted for by pointing out that they took different positions with respect to the electromagnetic and mechanical approaches, that they had different conceptions of how to construct and evaluate scientific theories, and that they had different conceptions of how to construct interpretations of the laws of electromagnetism.[36]

The main difference between (Fac)-(Ind) and (Con)-(Tra) thus comes down to the following. Adherents of (Fac)-(Ind) assume that the epistemological role of STEs

---

[34] With an extra section for the American response between 1912 and 1980.

[35] Similar approaches to the reception of the theory of special relativity can be found in e.g. Glick (1987), Jungnickel and McCormmach (1990) or Richard Staley (2008).

[36] See among others Nersessian (1984, 113 - 119) for a good overview of Lorentz's longlasting adherence to the ether as the electrodynamical absolute frame of reference.

consists in establishing knowledge about the world, and they believe that philosophers should explain this by reference to generic individuals contemplating the STE. (Con)-(Tra), by contrast, does not place any a priori restrictions on the epistemological effect of STEs: this is a question that can only be answered on a contextual case-to-case basis, by looking at the transformations that occur because of the STE's formulation, presentation and reception. Approaching STEs in this way has a few implications that, we believe, could be beneficial for the contemporary philosophical debate.

First of all, the approach formulated here is schematic. In our discussion of Einstein's STE, we have focused on three contextual elements: the Maxwell-Lorentz theory of electromagnetism, the individual scientist Albert Einstein and the fundamental physics-community. It could well be, however, for this case or for others, that other contextual features deserve our attention as well. Miller, for example, refers to debates about electromagnetic induction in the engineering community at the time (1981, 154 – 156); Peter Galison (2003) has provided a very detailed and extensive account about the technology employed for measuring time and simultaneity in the period of Einstein's publication. All such contextual features could be included in our analysis as well. Accordingly, this approach leaves open the different changes that can occur: the notion of scientific context is flexible (without being an empty box, we contend). It allows for changes on different levels according to the historical situation in which the STE in question was formulated and presented.

A second, related implication is that going (Con)-(Tra) makes room for methodological pluralism. This is an advantage, because it may allow one to approach debates such as the one between Brown and Norton from new angles. Between 1986 and 2005 they have argued against each other's approach by coming up with STEs from the history of science that they believed could only be explained by their own approach — platonism and empiricism, respectively — , and not by the other. Up until now, however, there has not been any clear winner.[37] The fact that this debate

---

[37] See e.g. Brown's *Why Thought Experiments Transcend Experience* (2004) and Norton's *Why*

has been going on for such a long time, without any real end conclusion, suggests that it is difficult — if not impossible — to argue convincingly that either platonic inferential leaps or empiricist argument-reductions are the final philosophical word on STEs. If, on the other hand, we situate the epistemological effect of the STE within an appropriate scientific context, we need not assume that there is one single mechanism that explains the whole effect of every possible STE. Einstein's focus on principles, together with his insight about the relative existence of the electric field, explains, for example, why the magnet-conductor STE brought Einstein to raise the principle of relativity from the status of a conjecture to the status of a postulate. Yet this cannot explain why certain other scientists did not follow Einstein in taking the asymmetry to suggest that an interpretation of the laws of electromagnetism without an ether was possible. To explain this, we would need a mechanism that refers to their work on the foundations of physics, or to their institutional background, or ... Rather than searching for the one true mechanism underlying all STEs — as Brown and Norton seem to do — we believe it to be more fruitful to see these mechanisms as philosophical tools that allow us to explain why certain changes occurred in the scientific context because of a particular STE.

A final advantage is that the approach can incorporate *parts* of the (Fac)-(Ind) approach. It is perfectly well possible that a particular STE brings about knowledge of the world for a particular scientist, and that this can be explained by an inductive argument. This would mean that there are elements within the scientific context which explain why this scientist reads this particular STE as an inductive argument. What our approach does not allow for, however, are broad and generalizing claims: it does not support the claim that all STEs *in general* have the same epistemological effect on *every* individual contemplating them.

We would like to end with two concluding remarks. First: the approach sketched above is not without risks. Introducing the notion of context could imply the danger

---

Thought Experiments Do Not Transcend Experience (2004b), and the fact that Brown, in the second edition of his book on STEs (2010, 46 – 48) still uses the same arguments against Norton's approach.

of overcontextualization. Any historical element could become part of the STE's context. A possible consequence could be that the same STE has radically different epistemological effects for different philosophers, depending on what they take to be the relevant context. Moreover, contextualization could also lead to the STE's "extinction": the STE would then become nothing more than a small part of a much bigger story, which leaves us with the question whether we are still really studying STEs.

While these are possible risks of the approach presented here, the notion of context is not a catch-all term: for every particular element that we want to include in an STE's scientific context we have to provide good (historical) reasons. This makes us believe that (Con)-(Tra) can provide a fruitful new approach to the philosophical study of the epistemological characteristics of STEs. The approach requires us to be explicit about the historical scientific context in which we want to study and analyse the functioning of the STE in question. As such, it provides us with a more stable ground for philosophical disputes about the epistemological specifics of scientific TEs.

Second: does one single case suffice to make our point? Strictly speaking one case may suffice to show that a position has shortcomings (if it fails to capture important characteristics of that case). In other words, if our case – which was in itself an important STE in the history of physics – shows that (Fac)-(Ind) is too narrow, we have already made some progress. One case of course does not suffice to show that our (Con)-(Tra) alternative itself is better in general. For that more cases would be needed. Given that (Con)-(Tra) requires that such cases are investigated with much attention to historical detail, that would be beyond the scope of the present paper. We leave the discussion of extra cases for further research.

References

Angel R. B. (1980). *Relativity: The Theory and its Philosophy.* Pergamom Press.

Armstrong D. (1983). *What is a Law of Nature?.* Cambridge University Press.

Arthur R. (1999). On Thought Experiments as A Priori Science. *International Studies in the Philosophy of Science 13*(3): pp. 215 – 229.

Bishop M. (1998). An Epistemological Role for Thought Experiments. In: Shanks N. (Ed.) *Idealization IX: Idealization in Contemporary Physics*, Rodopi: pp. 19 – 33.

Bishop M. (1999). Why Thought Experiments Are Not Arguments. *Philosophy of Science 66*: pp. 534 – 541.

Bokulich A. (2001). Rethinking Thought Experiments. *Perspectives on Science 9*(3): pp. 285 – 307.

Brown J. R. (1986). Thought Experiments since the Scientific Revolution. *International Studies in the Philosophy of Science 1*(1): pp. 1–15.

Brown J. R. (1991a). *The Laboratory of the Mind: Thought Experiments in the Natural Sciences*. Routledge.

Brown J. R. (1991b). Thought Experiments: A platonic account. In: Horowitz T. & Massey G. J. (Eds.) *Thought Experiments in Science and Philosophy*, Rowman and Littlefield, pp. 119–128.

Brown J. R. (1999). *Philosophy of Mathematics: An Introduction to the World of Proofs and Pictures*. Routledge.

Brown J. R. (2004). Why Thought Experiments Transcend Experience. In: Hitchcock C. (Ed.). *Contemporary Debates in Philosophy of Science*. Blackwell.

Brown J. R. (2010). *The Laboratory of the Mind: Thought Experiments in the Natural Sciences 2nd Edition*. Routledge.

Brown J. R. (2013). What Do We See in a Thought Experiment? In: Frappier M. Meynell L. Brown J. R. (Eds.). *Thought Experiments in Philosophy, Science, and the Arts*, Routledge, pp. 53 – 68.

Bunzl M. (1996). The Logic of Thought Experiments. *Synthese 106*(2): pp. 227 – 240.

Camilleri K. (2014). Towards a Constructive Epistemology of Thought Experiments in Science. *Synthese 191*(8): pp. 1697 – 1716.

Camilleri K. (2015). Knowing What Would Happen: The Epistemic Strategies in Galileo's Thought Experiments. *Studies in History and Philosophy of Science*, `http://dx.doi.org/10.1016/j.shpsa.2015.08.009`.

Clement J. (2009). The Role of Imagistic Simulation in Scientific Thought Experiments. *Topics in Cognitive Science 1*(4): pp. 686 – 710.

Corry L. (1997). Hermann Minkowski and the Postulate of Relativity. *Archive for History of the Exact Sciences 51*(4): pp. 273 – 314.

Darrigol O. (1996). The Electrodynamic Origins of Relativity Theory. *Historical Studies in the Physical and Biological Sciences 26*(2): pp. 241 – 312.

Darrigol O. (2002). *Electrodynamics from Ampère to Einstein.* Oxford University Press.

Darrigol O. (2006). The Genesis of the Theory of Relativity. In: Damour, T. et al. (Eds.). *Einstein, 1905 – 2005.* Birkhäuser.

De Mey T. (2003). The Dual Nature of Thought Experiments. *Philosophica 72*: pp. 61 – 78.

De Mey T. (2006). Imagination's Grip on Science. *Metaphilosophy 37*(2): pp. 222–239.

Dretske F. (1973). Laws of Nature. *Philosophy of Science 44*: pp. 248–268.

DiSalle R. (2006). *Understanding Space-Time: The Philosophical Development of Physics from Newton to Einstein.* Cambridge University Press.

DiSalle R. (2009). Space and Time: Inertial Frames. In: Zalta E. N. (Ed.) *The Stanford Encyclopedia of Philosophy.* `http://plato.stanford.edu/entries/spacetime-iframes/`

Einstein, A. (1905). On the Electrodynamics of Moving Bodies. In: Stachel, J. et al. (Eds.) *The Collected Papers of Albert Einstein Volume 2. The Swiss Years: Writings, 1900 – 1909 (English Translation).* Princeton University Press.

Einstein A. (1919). Time, Space and Gravitation. *The London Times*, November 28.

Einstein A. (1922). *Ether and the Theory of Relativity.* Methuen & Co. `www-groups.dcs.st-and.ac.uk/history/Extras/Einstein_ether.html`

Einstein A. (1923). *The Principle of Relativity: A Collection of Original Memoirs on the Special and General Theory of Relativity.* Dover Publications.

Einstein A. (1934). On the Method of Theoretical Physics. *Philosophy of Science 1*(2): 163 – 169.

Ferraro R. (2007). *Einstein's Space-Time: An Introduction to Special and General Relativity.* Springer.

Flores F. (1999). Einstein's Theory of Theories and Types of Theoretical Explanations. *International Studies in the Philosophy of Science 13*(2): pp. 123 – 134.

Galison P. (2003). *Einstein's Clocks, Poincaré's Maps: Empires of Time.* W. W. Norton & Company.

Gendler T. S. (1998). Galileo and the Indispensability of Scientific Thought Experiment. *The British Journal for the Philosophy of Science 49*(3): pp. 397–424.

Gendler T. S. (2000). *Thought Experiment: On the Powers and Limits of Imaginary Cases.* Routledge.

Gendler T. S. (2004). Thought Experiments Rethought - and Reperceived. *Philosophy of Science 71*: pp. 1152 – 1163.

Glick T. (1987). *The Comparative Reception of Relativity*. D. Reidel Publishing Company.

Goldberg S. (1984). *Understanding Relativity: Origin and Impact of a Scientific Revolution*. Clarendon Press.

Gooding D. (1992). What is Experimental About Thought Experiments? *PSA: Proceedings of the Bieannial Meeting of the Philosophy of Science Association 2*: pp. 280 – 290.

Gooding D. (1994). Imaginary Science. *The British Journal for the Philosophy of Science 45*(4): pp. 1029 – 1054.

Hacking I. (1992). Do Thought Experiments Have a Life of Their Own? *PSA: Proceedings of the Bieannial Meeting of the Philosophy of Science Association 2*: pp. 302 – 308.

Häggqvist S. (2009) A Model for Thought Experiments. *Canadian Journal of Philosophy 39*(1): pp. 55 – 76.

Hon G. & Goldstein B. R. (2005). How Einstein Made Asymmetry Disappear: Symmetry and Relativity in 1905. *Archive for History of Exact Sciences 59*(5): pp. 437 – 533.

Howard D. A. (2015). Einstein's Philosophy of Science. In: Zalta E. N. (Ed.) *The Stanford Encyclopedia of Philosophy*. `http://plato.stanford.edu/entries/einstein-philscience/#PriTheTheDis`

Janssen M. (2002a). Reconsidering a Scientific Revolution: The Case of Einstein Versus Lorentz. *Physics in Perspective 4*: pp. 421 – 446.

Janssen M. (2002b). *COI* Stories: Explanation and Evidence in the History of Science. *Perspectives on Science 10*(4): pp. 457 – 522.

Jungnickel C. & McCormach R. (1990) *Intellectual Mastery of Nature: Theoretical Physics from Ohm to Einstein – Volume 2: The Now Mighty Theoretical Physics 1870 – 1925*. University of Chicago Press.

Knudsen O. (1980) 19th Century Views on Induction in Moving Conductors. *Centaurus 24*: pp. 346 – 360.

Kosso P. (2003). Symmetry, Objectivity, and Design. In: Brading K. & Castellani E. (Eds.) *Symmetries in Physics: Philosophical Reflections*. Cambridge University Press: pp. 413 – 424.

Kuhn T. S. (1977). A Function for Thought Experiments. In: *The Essential Tension: Selected Studies in Scientific Tradition and Change*. The University of Chicago Press, pp. 240–265.

Lorentz, H. A. (1895) *Versuch einer Theorie der elektrischen und optischen Erscheinungen in bewegten Körpern*. Brill.

Mach E. (1897). *Über Gedankenexperimente*. Springer.

Martin C. A. (2003). On Continuous Symmetries and the Foundations of Modern Physics. In: Castellani E. & Brading K. (Eds.) *Symmetries in Physics: Philosophical Reflections*. Cambridge University Press: pp. 29 – 60.

McAllister J. W. (1996). The Evidential Significance of Thought Experiments in Science. *Studies in the History and Philosophy of Science 27*(2): pp. 233 – 250.

McAllister J. W. (2004) Thought Experiments and the Belief in Phenomena. *Philosophy of Science 71*(5): pp. 1164 – 1175.

McChormach R. (1970). H. A. Lorentz and the Electromagnetic View of Nature. *Isis 61*(4): pp. 459 – 497.

Miller A. I. (1981). *Albert Einstein's Special Theory of Relativity: Emergence (1905) and Early Interpretation (1905 – 1911).* Addison-Wesley Publishing.

Miller A. I. (1986). *Frontiers of Physics: 1900 – 1911.* Birkhäuser.

Nersessian N. (1984). *Faraday to Einstein: Constructing Meaning in Scientific Theories.* Kluwer Academic Publishers.

Nersessian N. (1990). Methods of Conceptual Change in Science: Imagistic and Analogical Reasoning. *Philosophica 45*: pp. 33 – 54.

Nersessian N. (1991) Why Do Thought Experiments Work? *Proceedings of the Cognitive Science Society 13*: pp. 430 – 438.

Nersessian N. (1992) In the Theoretician's Laboratory: Thought Experimenting as Mental Modelling. *PSA: Proceedings of the Bieannial Meeting of the Philosophy of Science Association 2*: pp. 291–301.

Nersessian N. (1999) Model-Based Reasoning in Conceptual Change. In: Magnani L. Nersessian N. & Thagard P. (Eds.) *Model-Based Reasoning in Scientific Discovery*, Kluwer Academic/Plenum Publishers: pp. 5 – 22.

Nersessian N. (2007). Thought Experimenting as Mental Modeling: Empiricism without Logic. *Croatian Journal of Philosophy 20*: pp. 125 – 161.

Norton J. (1991). Thought Experiments in Einstein's Work. In: Horowitz T. & Massey G. J. (Eds.) *Thought Experiments in Science and Philosophy*, Rowman and Littlefield, pp. 129–148.

Norton J. (1996). Are Thought Experiments Just What You Thought? *Canadian Journal of Philosophy 26*(3): pp. 333–366.

Norton J. (2000). 'Nature is the Realisation of the Simplest Conceivable Mathematical Ideas': Einstein and the Canon of Mathematical Simplicity. *Studies in History and Philosophy of Modern Physics 31*(2): pp. 135 – 170.

Norton J. (2004a) On Thought Experiments: Is There More to the Argument? *Philosophy of Science 71*: pp. 1139–1151.

Norton J. (2004b) Why Thought Experiments Do Not Transcend Empiricism. In: Hitchcock C. (Ed.) *Contemporary Debates in Philosophy of Science*, Blackwell, pp. 44–66.

Norton J. (2004c). Einstein's Investigations of Galilean Covariant Electrodynamics Prior to 1905. *Archive for History of Exact Sciences 59*(1): pp. 45 – 105.

Norton J. (2010). How Hume and Mach Helped Einstein Find Special Relativity. In: Domski M. & Dickinson M. (Eds.) *Discourse on a New Method: Reinvigorating the Marriage of History and Philosophy of Science*. Open Court.

Norton J. (2013). Chasing the Light: Einstein's Most Famous Thought Experiment. In: Brown J. R. Frappier M. & Meynell L. (Eds.) *Thought Experiments in Philosophy, Science and the Arts*. Routledge.

Norton J. (2014). Einstein's Special Theory of Relativity and the Problems in the Electrodynamics of Moving Bodies that Led Him to It. In: Janssen M. & Lehner C. (Eds.) *Cambridge Companion to Einstein*. Cambridge University Press.

Poincaré H. (1906). Sur la Dynamique de l'électron. *Rendiconti del Circolo Matematico di Palermo 21*(1): pp. 129 – 175.

Popper K. (1959). *The Logic of Scientific Discovery*. Hutchinson.

Rescher N. (1991). Thought Experiments in Presocratic Philosophy. In: Horowitz T. & Massey G. J. (Eds.) *Thought Experiments in Science and Philosophy*, Rowman and Littlefield, pp. 31–42.

Rynasiewicz R. (1998). The Construction of the Special Theory: Some Queries and Considerations. In: Howard D. (Ed.) *Einstein: The Formative Years 1879 – 1909*, Einstein Studies vol 8, Birkhäuser.

Stachel J. (2002). “What Song the Syrens Sang”: How Did Einstein Discover Relativity? In: *Einstein from ’B’ to ’Z’*. Springer.

Stachel J. (2005). Fresnel’s Dragging Coefficient as a Challenge to the 19th Century Optics of Moving Bodies. In: Kox A. J. & Eisenstaedt J. (Eds.) *The Universe of General Relativity*, Einstein Studies, Birkhäuser.

Stachel J. & Janssen M. (2004) The Optics and Electrodynamics of Moving Bodies. *Max-Planck-Institut für Wissenschaftgeschichte Preprints volume 265*.

Staley R. (2008). *Einstein’s Generation: The Origins of the Relativity Revolution*. The University of Chicago Press.

Tooley M. (1977). The Nature of Laws. *Canadian Journal of Philosophy 7*: pp. 667 – 698.

Urbaniak R. (2012). Platonic Thought Experiments: How on Earth? *Synthese 187*(2): pp. 731 – 752.

Wolters G. (2012). Mach and Einstein, or, Clearing Troubled Waters in the History of Science. In: Lehner, C. Renn, J. & Schemmel, M. (Eds.) *Einstein and the Changing Worldviews of Physics*, Einstein Studies, Birkhäuser.