Scientific Explanation between Principle and Constructive Theories

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The aim of this article is to analyze the role of the distinction between principle and constructive theories in the question of the explanatory power of special relativity. We show how the distinction breaks down at the explanatory level. We assess Harvey Brown's claim that, as a principle theory, special relativity lacks explanatory power. We argue that this claim is based on an unrealistic picture of the kind of explanations provided by principle (and constructive) theories. Finally, we argue that the structural account of explanation captures the explanatory success of special relativity.

1. Introduction. In defense of his claim of the necessity of a dynamical theory of space-time, Brown (Brown 2005; Brown and Pooley 2006; Brown and Timpson 2006) often appeals to the distinction between principle and constructive theories and to special relativity's character as a principle theory. We can summarize Brown's argument as follows: (1) the geometrical explanations provided by special relativity (SR) are not constructive theory explanations; (2) principle theories lack the explanatory power of constructive theories; ergo, (3) we still do not have a genuine explanation of relativistic effects such as length contraction. The latter can be fully provided only by a constructive theory.

The main aim of this article is to analyze the actual role of the distinction between principle and constructive theories in the question of the explanatory power of SR. In particular, we assess the use that Brown makes

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of the dichotomy and criticize it as presupposing an overly narrow idea of the kind of explanations provided by principle theories.

Although this article takes SR as a case study, our analysis more generally concerns the way in which the principle/constructive distinction enters the philosophical discussion about scientific explanation. A significant part of the arguments below could therefore also be applied, mutatis mutandis, to other case studies.[1]

We take the view that, as a well-established scientific theory, SR successfully explains relativistic phenomena. We put forward the claim that SR does so by providing *structural explanations*, a kind of mathematical explanation that was originally described by Hughes (1989a, 1989b). Section 2 is therefore devoted to a brief summary of the structural account of explanation.

Some of Brown's reproaches to geometrical explanations in SR rely on the characterization by Balashov and Janssen (2003) of the explanations provided, respectively, by principle and constructive theories (henceforth, principle and constructive explanations). In section 3, we assess the tenability of such a characterization, together with Brown's arguments hinging on it. Section 4 investigates the role played by the geometry of spacetime in the explanation of the kinematic behavior of bodies and provides an answer to Brown's challenge for the genuine nature of mathematical explanations. Section 5 assesses the claim that, even acknowledging the explanatory power of the geometrical accounts, one should still expect to find a deeper explanation, which would explain the structure of spacetime from the properties of matter. Finally, section 6 provides more general considerations about the legitimacy of normative arguments in the theory of scientific explanation.

2. Structural Explanation. Before we start, we must put our cards down and spend a couple of words on a notion that is used throughout this article. This is a special kind of mathematical explanation in physics, hypothesized by R. I. G. Hughes, that he called structural explanation. A minimal definition of structural explanation is briefly provided by Clifton: "We explain some feature B of the physical world by displaying a mathematical model of part of the world and demonstrating that there is a feature A of the model that corresponds to B" (1998, 7). In our understanding of Hughes's account, the central feature of structural ex-

1. For instance, it could be applied to Jeff Bub's interpretation of quantum theory as a principle theory.

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planation lies in the fact that its validity is independent of the question of what *categorial framework* underlies the theory of reference.[2]

From the very beginning, structural explanation was thought to be relevant to explanation within quantum theory. As an illustration, take the case of the uncertainty relation between position (p) and momentum (q; Dorato and Felline 2010a; Felline 2010). The existence of a minimum for the product of the uncertainties of these two measurements, or the nonsimultaneous sharpness possessed by the two observables, represented formally as

$$\Delta x \, \Delta p = \frac{\hbar}{2}, \tag{1}$$

is explained structurally by showing that, in the Hilbert space of square integrable functions (the mathematical model), the formal representative $\Psi (p_x, p_y, p_z)$ of the distribution of the observable momentum is the Fourier transform of the function $\Psi (x, y, z)$, the formal representative of the distribution of probability for the position. Consequently, the structural explanation of the uncertainty relation exploits a well-known mathematical property of the Fourier transform: the narrower the interval in which one of the two functions differs significantly from zero, the larger is the interval in which its Fourier transform differs from zero, in such a way that equation (1) must be satisfied.

The possibility of explaining physical phenomena with a mathematical model is based on the *representation relation* between the model and the target system. Such a relation more generally allows for the performance of *surrogative reasoning*, that is, to learn something about a target by investigating the model.[3]

In the case of quantum theory, one of the most important virtues of structural explanation is that, notwithstanding the lack of an uncontroversial interpretation of the theory, it still enables quantum theory to provide genuine explanations and understanding of phenomena. Notice that, far from diminishing the explanatory power of quantum theory, this 'agnostic' character is a virtue of structural explanation. By being free from any metaphysical assumption about the world, structural explanation escapes the charge posed by Duhem—according to which scientific explanations are always metaphysical (Hughes 1989a)—and is indepen-

2. A categorical framework is the set of fundamental metaphysical assumptions about what sorts of entities and what sorts of processes lie within a theory's domain (Hughes 1989b).

3. I mostly draw from Hughes's denotation demonstration interpretation account of scientific representation (1997). The term surrogative reasoning is taken from Swoyer (1991).

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dent of previous metaphysical assumptions that could be unjustified (or even dangerously inadequate) within a completely new theoretical framework. Moreover, structural explanations can survive theory change more stably than constructive explanations, with their ontological baggage.

While the idea of structural explanation has been mostly developed with quantum mechanics in mind, both Hughes and Clifton use SR as a template for a theory that provides structural explanations (see also Dorato and Felline 2010b):

> Suppose we were asked to explain why one particular velocity (in fact the speed of light) is invariant across the set of inertial frames. . . . [The Lorentzian] causal explanation is now seen as seriously misleading; a much better answer would involve sketching the models of space-time which special relativity provides and showing that in these models, for a certain family of pairs of events, not only is their special separation x proportional to their temporal separation t, but the quantity x/t is invariant across admissible (that is, inertial) coordinate systems; further, for all such pairs, x/t always has the same value. This answer makes no appeal to causality; rather it points out structural features of the models that special relativity provides. It is, in fact, an example of a structural explanation. (Hughes 1989b, 256–57)

Next we argue, contra Brown, that, if conceived of as structural explanations, the explanations provided by SR are genuine and successful.

3. Explanations in Principle and in Constructive Theories. In this section we assess the characterization of the dichotomy as given by Balashov and Janssen (2003), as it seems to be acknowledged in some of the arguments put forward by Brown (see Brown and Pooley 2006, n. 9). The aim of this section is to show that there is nothing like a 'principle (or constructive) explanation' in the sense of Brown (sec. 3.1). To the extent to which it is possible to isolate a unifying feature of principle explanations (sec. 3.2), this feature alone does not imply a lack of explanatory power (sec. 3.3).

Balashov and Janssen state:

> In a theory of principle . . . one explains the phenomena by showing that they necessarily occur in a world in accordance with the postulates. Whereas theories of principle are about the *phenomena*, constructive theories aim to get at the underlying *reality*. In a constructive theory one proposes a (set of) model(s) for some part of physical reality. . . . One explains the phenomena by showing that the theory

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provides a model that gives an empirically adequate description of the salient features of reality.

Consider the phenomenon of length contraction. Understood purely as a theory of principle, SR explains this phenomenon if it can be shown that the phenomenon necessarily occurs in any world that is in accordance with the relativity postulate and the light postulate. By its very nature such a theory-of-principle explanation will have nothing to say about the reality behind the phenomenon. A constructive version of the theory, by contrast, explains length contraction if the theory provides an empirically adequate model of the relevant features of a world in accordance with the two postulates. Such constructive-theory explanations do tell us how to conceive of the reality behind the phenomenon. (2003, 331)

3.1. Deductive-Nomological against Model-Based Explanations, and the Reality behind Phenomena. A very first feature of the characterization above is that constructive explanations are based on models of phenomena, while principle explanations use a deductive-nomological (DN) method. It seems clear that when Brown argues how little the principle explanation explains, he often has in mind such a DN model of explanation in SR. This is evident, for instance, when, after identifying the explanation provided by SR of length contraction with Einstein's original derivation of the latter from the two fundamental postulates, Brown and Pooley conclude: "What has been shown is that rods and clocks must behave in quite particular ways in order for the two postulates to be true together. But this hardly amounts to an explanation of such behaviour" (2006, 7).

So, what are we to make of this first claim, that principle theories explain by deducing the explanandum from the fundamental postulates? Is there any reason to think that scientific explanations always trace out the method with which the scientific theory of reference has been built? Neither Balashov and Janssen nor Brown and Pooley (in their discussion of Balashov and Janssen [2003]) provide any warrant for this assumption. Moreover, providing a DN version of a scientific explanation, as Brown and Pooley do in the passage referred to above, is an easy game to play—and not only within principle theories but also within constructive theories. The example, therefore, is not really pressing.

What about the claim that only constructive theories provide model-based explanations? At the end of the day, all scientific theories provide models for the representation of the processes and systems they study. With these models in hand, principle, as well as constructive, theories can provide model-based explanations.

In the specific case of SR, the resulting models are geometrical models

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representing the geometrical properties of space-time. Furthermore, in the pluralistic view of explanation assumed in this article, there is no reason to consider an explanation hinging on an abstract, mathematical model less explanatory than, say, an explanation hinging on a causal model. Indeed, the fact that mathematical models can work as a basis for scientific explanation is exactly the core of the structural account of explanation.

In the quotation above, the secondary claim is also present that "by its very nature . . . a theory-of-principle explanation will have nothing to say about the reality behind the phenomenon." However, this claim is, as it is, false. To be sure, a principle theory derives its structure from general phenomenological principles, but from this point of departure it reconstructs claims about the world and models the reality it describes. Thermodynamics claims that isentropic processes are always adiabatic processes; SR makes claims about the relation between energy and rest mass.

A possible understanding of the qualification 'behind the phenomenon' could be that while constructive theories are about unobservable reality, principle theories are about observable reality. However, the fact that the theory hinges on phenomenological principles does not imply that the former cannot go beyond this 'superficiality' and investigate the 'deeper' aspects of reality. Again, think of the great result $E = mc^2$ in SR. Finally, it is dubious that this characterization could help clear up the features of the proposed dichotomy, due to the controversial status of the observable/unobservable dichotomy.

3.2. Ontological Commitments. Let's start all over again. There is no reason to think that principle theories only provide DN explanations or that they concern phenomena rather than their underlying reality. In this subsection we give our reconstruction of the characterizing features of principle versus constructive explanation and show how, on the one hand, it is more faithful to Einstein's original distinction between principle and constructive theories, and, on the other, it could make sense of some of the arguments put forward by Brown and Pooley.

Einstein's dichotomy is basically methodological, concerning the kind of founding postulates and the analytical versus synthetic method used in building the structure of the theory. Just from this, it could be said that the constructive-synthetic method starting from hypothetically constructed elements typically carries more ontological assumptions than the analytic method starting from phenomenological postulates, characterizing principle theories. If this is right, the distinction between principle and constructive explanation could rather be characterized as concerning the degree to which they are committed to a categorical framework at the foundation of the explaining theory. According to this understanding

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of the distinction, while a constructive theory can provide what Salmon (1984) called an ontic explanation, this is not so for a principle theory. Just to give an example, a constructive explanation conceived in this way could exploit the ontological status of space-time as a substance existing independently of things and processes or as the cluster of properties and relations between bodies, which do not exist independently of the latter.

Notice how under this interpretation of the dichotomy, one could make (some—but see the next subsection) sense of Brown and Pooley's disagreement with Balashov and Janssen, pivoting on the question of whether the geometrical explanations of SR could be provided with a 'constructive' version. Reformulated according to the proposed reading, the question would mean, Can we formulate an ontic version of the geometrical explanations provided by SR?

Furthermore, one can equally make sense of the parallel question of the interpretation of SR either as a principle or as a constructive theory. From the point of view of the current article, this dispute is quite odd—given that, according to Einstein's methodological distinction, SR is a principle theory, period. But if we rephrase it according to the proposed 'interpretation', the core of the dispute is as follows: only if one can provide an ontic version of SR's geometrical explanations, then SR can be interpreted as a successful (insofar as it is explicative) constructive theory.[4]

3.3. A Relevant Distinction? We claimed that the proposed reading of the dispute between Balashov and Janssen and Brown and Pooley can make sense of some of the latter's arguments. In this subsection we show that, if we are right in our reconstruction, Brown's and Pooley's arguments still remain erroneous in different ways: to the extent to which something like a principle or a constructive explanation exists, this distinction does not allow the inference to Brown's and Pooley's conclusions.

First, as we have already said, according to Einstein's original distinction SR is a principle theory. This in turn implies that the attempt to translate its geometrical explanations into ontic explanations (where the ontology of space-time plays a special role) necessarily misunderstands the meaning of the geometrical account. We see the practical consequences of such a misunderstanding in the next sections. Second, one has to keep in mind that the distinction is in no way categorical, as constructive

4. In Brown (2005), chap. 8.2, the question is manifestly put in these terms. The same cannot be said, though, about Balashov and Janssen (2003) and Janssen (2007).

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theories always display principle elements and vice versa.[5] This implies that it is not true that only principle theories can provide 'ontologically agnostic' explanations, as also within constructive theories this kind of explanation can be useful and successful. This is the case for quantum theory but also for Pincock's abstract explanations (2007) or, to some extent, for Batterman's asymptotic explanations (2002). Third, given what has been said in section 2, it can well be not only that an agnostic explanation is satisfactory but that it is the most effective explanation even in the face of an alternative ontic explanation. For instance, the former could have a more general range of application or would be more stable than the latter under theory change. In our case, the use of classical electrodynamics to explain the Lorentz contraction constructively is unstable since we know that it is not the true theory.

Of course, Brown's response could be that even though we know classical electrodynamics is not the final theory of matter, we do know that whatever that final theory is, it is Lorentz covariant and approximated by classical electrodynamics. Therefore, we do know that we can explain the Lorentz contraction constructively in it. But the above amounts to saying that, whatever the theory of matter is that accounts for the behavior of bodies, it is Lorentz covariant, and from that covariance the Lorentz contraction follows—and what we have just sketched is exactly a principle (in the sense of ontologically agnostic) explanation.[6]

4. The Dormitive Virtue. Following Brown and Pooley (2006), within a constructive interpretation of SR, the explanatory role of space-time is supposed to lie in its 'action' on material bodies, for instance, 'shaping' rods. However, their argument goes, this account of length contraction presupposes an interpretation of space-time as a 'special entity' 'acting' on bodies without being affected by them, violating in this way the action-reaction principle. The ontological characterization of space-time coming out from this picture is unacceptable, and, they conclude, SR cannot be given a constructive interpretation.

The questionable premise of this argument, that the sole explanatory role conceived for space-time is causal, has already been criticized elsewhere (Dorato 2007; Hagar 2008). Here, we want to point out that the hypothesis put forward in the previous section—that with 'constructive explanations' one has to read 'ontic explanation'—accounts well also for the implicit premise of the above argument that explanatorily relevant

5. That the principle/constructive distinction is not categorical is admitted by Brown in Brown and Timpson (2006, 32), whose arguments and conclusions, though, seem to us to conflict with this intuition.

6. I owe this point to a suggestion from John Norton.

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means causally relevant. Probably the most serious problem for Salmon's ontic conception is that it does not isolate the explanatorily relevant facts from the irrelevant ones. The most natural completion of the ontic conception (and the one adopted by Salmon) is therefore that the explanatorily relevant facts are those that are causally relevant. Thus, on our proposed understanding of Brown's constructive explanations, we can account for Brown's belief that the only constructive explanatory role for space-time is a causal role.

The rest of this section focuses on Brown and Pooley's criticism that it is not clear how the structure of space-time does more explanatory work than Moliere's dormitive virtue in opium (2006, 13). The objection refers to the claim that space-time geometry is but a codification of certain key aspects of the kinematics of bodies (4), in the same way that Moliere's dormitive virtue is nothing but a restatement of the explanandum phenomenon, with no additional information or enhancement of knowledge.

Admittedly this objection hits structural explanation where it hurts: the discussion about how mathematics can play a role in the explanation of physical phenomena is far from being exhausted. However, it is also far from groping in the dark. As a start, in order to allow for the production of novel knowledge with the surrogative reasoning performed on them, models must have an internal dynamics that is independent of the known structure of the target but that allows the subject to perform deductions and therefore draw conclusions about the system (Hughes 1997). In our case—where the surrogative reasoning exploits the mathematical properties of the models displayed by the theory—the role of the internal structure of the model is to allow us to be guided in our inquiries by well-confirmed laws and properties, which are the laws and properties of the mathematical model (see Pincock 2007).

So, Brown and Pooley wonder how the structure of space-time does more explanatory work than Moliere's dormitive virtue in opium. Our answer is that in appealing to Minkowskian geometry, and in virtue of the representation relation between the mathematical model and the target, one can exploit the more solid mathematical knowledge that we have of the geometrical model as if it were knowledge of the structural relations of the target. It seems to us that this is precisely how Brown himself uses the geometry of space-time to explain the twin effect in SR: clocks measure lengths in Minkowski geometry (hence, the image of a hodometer on the cover of Brown's book).

Moreover, it is exactly the use of a mathematical language that allows us to investigate the properties of the target while remaining ignorant about many of its features. Since what is relevant here are the geometrical properties of space-time and the fact that they are instantiated by our

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world, the same account could be held within both a relational and a substantivalist view of space-time.

5. The Cart before the Horse. As yet, one could acknowledge the explanatory power of SR but still ask for a dynamical explanation of space-time properties. It could be argued, in fact, that the explanations provided by SR are completely satisfactory only if one assumes the fundamentality of the space-time structure. Otherwise, there would always be scope for and, indeed, necessity of a more fundamental theory explaining the structure of space-time. However, so the argument goes, due to the ontic 'agnosticism' innate in principle theories, SR's belonging to this category makes it impossible to claim that the geometry of space-time represents a fundamental structure.[7] Therefore, the argument continues, either SR is provided with a constructive interpretation (like the one criticized by Brown [2005], chap. 8.2)—which we do not want—or it leaves a gap that could be filled by a fundamental (constructive) theory of matter underpinning the properties of space-time. Finally, from such a constructive theory will result a deeper and more satisfactory explanation, following the arrow of ontological priority.

In order to answer this last argument, notice first of all that the claim about the necessity of a deeper (constructive) explanation hinges on the hypothesis of an ontological priority of properties of matter over space-time, whose plausibility is yet to be proved. Second, while we have acknowledged that constructive theories tend to carry with them more ontological assumptions, the question of the fundamentality of a theory is never straightforward, within both constructive and principle theories. This is also because the answer to such a question never only depends on the theory itself but on the whole rest of scientific background knowledge.

So, in the light of our background scientific knowledge, do we have good reasons to think that a theory of matter more fundamental than SR is in sight? Hitherto, all signs rather suggest a negative answer and that space-time properties are to be considered as fundamental. Our best theory of matter is not even close to reconstructing the geometrical properties of space-time, and, further, we have convincing arguments denying the ontological priority of matter on space-time properties or showing the difficulties that a constructive theory of the kind advocated by Brown

7. "As long as we view SR strictly as a theory of principle in the sense in which it was defined above, there are no grounds for preferring one constructive-theory explanation over another" (Balashov and Janssen 2003, 10). Here the two constructive-theory explanations are Balashov and Janssen's 'orthodox' view and the neo-Lorentzian view.

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would run into (Hagar 2008; Norton 2008). If it is therefore surely true that principle theories in general might be completed by complementary, more fundamental constructive theory, the fact that this is also the case for SR is far from plausible.

6. Conclusion. We have proposed an analysis of how the distinction between principle and constructive theories could enter the evaluation of the explanatory power of a scientific theory. We have especially focused on the claim (put forward in particular in Brown and Pooley [2006]) that, due to its nature as a principle theory, Einstein's SR leaves an explanatory gap, which is to be filled by a dynamical theory of space-time. The general conclusion of the arguments here proposed is that Brown and Pooley use too many unwarranted assumptions about explanations in principle and in constructive theories, assumptions that undermine their account of explanation in SR. SR's explanations are not mere deductions or fallacious causal explanations or fallback explanations in view of a forthcoming complete explanation. Nothing in SR's being a principle theory implies any of these claims.

Given that our analysis is purely at the level of the theory of scientific explanation, a more straightforward defense of the explanatory power of SR could have invoked a full-blown account of mathematical explanations in physics. Alas, we still lack it. However, there is yet a more general answer that one could give to Brown's (and Pooley's) arguments. What we think results from our analysis is that Brown's first mistake consists in the attempt to apply traditional accounts of explanation to SR and to conclude, from the fact that SR does not conform to them, that SR does not explain. Rather, the most logical conclusion to be drawn is of the inadequacy of traditional standards of explanation in the case of SR. What we think these kinds of arguments show is that, given the current state of the art, the theory of scientific explanation is not in any condition to play a normative function and, therefore, to provide grounds for deciding on the adequacy of a well-established scientific theory.

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