Understanding & Equivalent Reformulations

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Abstract

Reformulating a scientific theory often leads to a significantly different way of understanding the world. Nevertheless, accounts of both theoretical equivalence and scientific understanding have neglected this important aspect of scientific theorizing. This essay provides a positive account of how reformulating theories changes our understanding. My account simultaneously addresses a serious challenge facing existing accounts of scientific understanding. These accounts have failed to characterize understanding in a way that goes beyond the epistemology of scientific explanation. By focusing on cases where we have differences in understanding without differences in explanation, I show that understanding cannot be reduced to explanation.

1 Introduction

Accounts of theoretical equivalence have neglected an important epistemological question about reformulations: how does reformulating a theory change our understanding of the world? *Prima facie*, improving our understanding is one of the chief intellectual benefits of reformulations. Nevertheless, accounts of theoretical equivalence have focused almost entirely on developing formal and interpretational criteria for when two formulations count as equivalent (Weatherall 2019a). Although no doubt an important question, focusing on it alone misses many other philosophically rich aspects of reformulation.

The burgeoning literature on scientific understanding would seem to be a natural home for characterizing how reformulations improve understanding. However, existing accounts of scientific understanding do not provide a clear answer. These accounts tend to focus on *competing* rather than *compatible* explanations, investigating how the best explanation provides understanding. This strategy neglects how equivalent formulations of the *same explanation* can provide different understandings. To address these gaps, I will show how theoretically equivalent formulations can change our understanding of the world.

Harkening back to Hempel, Kitcher, and Salmon, the *received view* of understanding holds that understanding why a phenomenon occurs simply amounts to grasping a correct explanation of that phenomenon (Strevens 2013; Khalifa 2017, 16ff). Many recent accounts of understanding have decried this picture as overly simplistic, arguing that genuine understanding goes well beyond grasping an explanation (Grimm 2010; Hills 2016; Newman 2017; de Regt 2017). Nevertheless, these critics of the received view still maintain a close connection between explanation and understanding, which Khalifa (2012, 2013, 2015) has exploited to systematically undermine their more expansive accounts. Defending what I'll call *explanationism*, Khalifa (2017) has argued that all philosophical accounts of understanding-why straightforwardly reduce to the epistemology of scientific explanation. Explanationism thereby poses a serious challenge to accounts of scientific understanding that seek to go beyond the traditional received view.

Here, I argue that we can refute explanationism by considering theoretically equivalent formulations. By definition, theoretically equivalent formulations agree completely on the way the world is, thereby describing the exact same state of affairs. Moreover, philosophers typically adopt an *ontic conception* of explanation, wherein explanations themselves correspond to states of affairs or propositions, e.g. the reasons why an event occurs.[1] By agreeing on the way the world is, equivalent formulations *ipso facto* provide the same explanations. Nonetheless, they can differ radically in the understandings that they provide. Thus, concerning many phenomena, theoretically equivalent formulations do not differ *qua* explanation, even as they differ *qua* understanding. These differences in understanding—without concomitant explanatory differences—make a separate account of understanding necessary.

Section 2 develops Khalifa's challenge for existing accounts of scientific understanding, showing how they reduce to accounts of explanation. I focus in particular on how Khalifa problematizes both skills-based accounts of understanding and a different strategy developed by Lipton (2009) that foreshadows my own. Section 3 demonstrates that theoretically equivalent formulations provide a large class of cases that meet Khalifa's challenge. In these cases, we have differences in understanding-why without differences in explanation. In Section 4, I introduce and defend *conceptualism* as a positive account of these differences in understanding. Conceptualism characterizes how these differences arise from differences in the presentation and organization of explanatory information. Although not a complete account of understanding, conceptualism can be adjoined with existing accounts to both meet Khalifa's challenge and accommodate reformulations. Section 5 considers and rebuts an objection to my use of theoretically equivalent formulations.

2 The challenge from explanationism

Traditional accounts of explanation defend a deflationary stance toward understanding. According to Khalifa, "on the old view, if understanding was not merely psychological afterglow, it was nevertheless redundant, being replaceable by explanatory concepts without loss" (2012, 17). Explanationism encapsulates this deflationary position:

> *Explanationism*: all philosophically significant aspects of understanding-why are encompassed by an appropriately detailed account of the epistemology of scientific explanation.[2]

Importantly, even non-deflationary accounts of scientific understanding must adopt some account of scientific explanation. Then, given whatever account of explanation is adopted, explanationism demands an argument that understanding-why does not reduce to claims about (this kind of) explanation. For this reason, explanationism is dialectically most effective when married with explanatory pluralism (Khalifa 2017, 8).[3] Then, no matter which account(s) of explanation is ultimately correct, explanationism challenges non-deflationary accounts of understanding on their own terms.

Khalifa defends explanationism by developing a detailed account of the epistemology of scientific explanation, which he calls the *explanation-knowledge-science* (EKS) model. According to this framework, an agent improves their understanding why *p* provided that they

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[1] For the ontic conception, see Salmon (1998 [1984], 325), Strevens (2008, 6), Craver (2014), and Skow (2016).

[2] In earlier work, Khalifa refers to this position as the *explanatory model of understanding* (2012, 17). Khalifa (2017, 85) uses "explanationism" in a narrower sense aimed at showing how objectual understanding can be reduced to explanatory understanding, ultimately defending what he calls "quasi-explanationism." For convenience, I simplify this more cumbersome terminology.

[3] Khalifa (2012, 19) claims that explanationism is compatible with explanatory monism, but only if the requisite unified theory of explanation accommodates all typical cases of explanation. It is not clear that such a theory exists.

either (i) gain a more complete grasp of *p*'s *explanatory nexus* or (ii) their grasp of this explanatory nexus more closely resembles *scientific knowledge* (Khalifa 2017, 14). Khalifa defines the *explanatory nexus* as the "totality of explanatory information about *p*," which includes all correct explanations of *p* and the relations between these explanations (2017, 6). I will return to the explanatory nexus in Section 3, arguing that knowledge of this nexus does not exhaust differences in understanding-why. Turning to *scientific knowledge*, Khalifa argues that this requires learning a correct explanation through a process of *scientific explanatory evaluation* (SEEing).[4] Scientific explanatory evaluation involves a three-step process of 1) considering plausible potential explanations, 2) comparing these potential explanations, and 3) deciding how to rank these potential explanations with respect to approximate truth (or at least saving the phenomena) (Khalifa 2017, 12-13). Khalifa uses this ordinary process of SEEing to deflate many anti-explanationist accounts of understanding.

To date, the main anti-explanationist strategy has been to argue that understanding-why involves special skills or abilities. Provided that these skills go beyond what's required for explaining or possessing knowledge-why, explanationism would be refuted.[5] Versions of this *skills-based* strategy include skills for grasping counterfactual information (Grimm 2010, 2014), "cognitive control" over providing and manipulating explanations (Hills 2016), and inferential skills used in making certain kinds of models (Newman 2013, 2017). de Regt has provided one of the most sustained defenses of the skills-based strategy, arguing that understanding involves the ability to make qualitative predictions using an intelligible theory that explains the phenomenon (de Regt and Dieks 2005; de Regt 2009a, 2017).

Khalifa's criticism of Grimm provides the most succinct illustration of explanationism in action. Khalifa argues that Grimm's (2010) account of understanding makes no advance over Woodward's (2003) account of explanation. According to Grimm, understanding is an ability to predict how changing one variable changes another variable, *ceteris paribus* (2010, 340-41). Yet, as Khalifa notes—and Grimm acknowledges (2010, 341; 2014, 339)—this kind of understanding is closely related to Woodward's analysis of "what-if-things-had-been-different questions." Hence, this kind of counterfactual reasoning ability is clearly part of scientific explanatory evaluation (SEEing). We already deploy counterfactual reasoning in considering and comparing alternative explanations, and explaining already involves the ability to answer these what-if questions (Khalifa 2017, 71, 74). Khalifa's response is easily generalized: if all that a theory of understanding adds is referencing a cognitive ability to use an explanation, then a theory of explanation can make the same move without modification.[6]

Another obvious anti-explanationist strategy would involve identifying cases of scientific understanding in the absence of an explanation. Such cases would, at first glance, show that accounts of explanation miss something about understanding. Undertaking precisely this strategy, Lipton (2009) considers a number of cases where we seemingly acquire the cognitive benefits of explanations without actually providing explanations. These cognitive benefits include knowledge of causes, necessity, possibility, and unification (2009, 44). Against the received view, Lipton identifies understanding not as "having an explanation," but rather with "the cognitive benefits that an explanation provides" (2009, 43). Notice that this still

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[4] Khalifa also requires that this belief-forming process be *safe*, i.e. sufficiently unlikely to lead to false beliefs.

[5] Some epistemologists have pursued other strategies, arguing that objectual understanding either does not reduce to understanding-why or else that some forms of objectual understanding do not even require explanatory understanding. Khalifa responds at length to these approaches (2017, 80ff).

[6] Khalifa (2012) applies this strategy to criticize de Regt and Dieks (2005) and de Regt (2009a, 2009b) in detail. Against Hills, Khalifa argues that her necessary conditions for understanding are either irrelevant for enhancing understanding or else they are captured by the EKS model (2017, 70-72). He responds to Newman in his (2015).

maintains a close connection between understanding and explanation.

Khalifa (2013) exploits this connection to argue that Lipton's strategy makes no fundamental advance over the explanation literature. Systematically examining each of Lipton's examples, Khalifa shows that whenever there is understanding through a non-explanation, there is an explanation that provides *that* understanding *and more*. This leads to what Khalifa calls "*explanatory idealism*" about understanding, which holds that "other modes of understanding ought to be assessed by how well they replicate the understanding provided by knowledge of a good and correct explanation" (2013, 162). Thus, a suitably detailed account of scientific explanation would provide the same insights about understanding that Lipton defends. In this way, explanation functions as the "*ideal* of understanding" (Khalifa 2013, 162). More recently, Khalifa (2017) has recast part of his criticism as what he calls the "right track objection." According to this objection, Lipton's examples involve agents who merely have a kind of "proto-understanding," wherein they are on the right track to acquiring an explanation and thereby understanding-why.

In the remainder of this essay, I defend a strategy that avoids Khalifa's objections against existing accounts of scientific understanding. My strategy succeeds where others fail for two reasons. First, I do not rely on positing any special abilities unique to understanding, so Khalifa's challenge from SEEing does not apply. Secondly, the examples I consider provide understanding through the same explanatory information, so explanatory idealism does not apply either.

3 Intellectual differences without explanatory differences

To refute explanationism, it suffices to identify differences in understanding-why between two presentations of the *same* explanation, since these appeal—*ipso facto*—to the same explanatory information. In such cases, understanding-why still arises from an explanation, but non-explanatory differences account for the corresponding differences in understanding. The features we ascribe to "understanding-why" and to "explanation" then truly come apart. For convenience, I will refer to differences in understanding as *intellectual differences*. This section aims to show that, *pace* explanationism, we can have intellectual differences without concomitant explanatory differences.

To forestall any hopes of a piecemeal explanationist rebuttal, my argument requires a sufficiently large class of examples stemming from scientific practice. As we will see, the recent literature on theoretical equivalence provides a rich set of cases, spanning many parts of physics. Nevertheless, some might worry that these mathematical reformulations are too isolated or special to be indicative of scientific understanding in general. Hence, it is worthwhile to also consider a more common aspect of scientific practice: diagrammatic reformulations. I will consider both cases in turn, illustrating each with a paradigmatic example.[7] Importantly, my argument does not apply to cases of different but *complementary* explanations, such as Salmon's example of causal-mechanical vs. unificationist explanations of a balloon moving forward upon takeoff in an airplane (Salmon 1998, 73; de Regt 2017, 77). Such complementary explanations appeal to different explanatory information and are hence genuinely different explanations. Khalifa's EKS model of understanding accommodates such cases since they reference different parts of the explanatory nexus (2017, 25).

By definition, *theoretically equivalent formulations* express the same scientific theory,

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[7] Reformulations of symmetry arguments provide another class of examples. See Hunt (forthcoming) for details.

agreeing exactly on the way the world is (or could be). Philosophers have defended a few different characterizations of theoretical equivalence, including definitional equivalence (Glymour 1971), model isomorphism (North 2009), and categorical equivalence (Halvorson 2016; Weatherall 2016; Barrett 2019). These accounts all seek to formalize the intuition that two formulations are theoretically equivalent if and only if they are mutually inter-translatable and empirically equivalent. Mutual inter-translatability requires that any thing expressed in one formulation can be expressed in the other without loss of physically significant information. Empirical equivalence requires that the formulations agree on all physically possible measurable consequences.

Recent defenses of categorical equivalence have shown it to be the most fruitful criterion for theoretical equivalence. It successfully formalizes a number of philosophically and scientifically plausible cases of theoretically equivalent formulations.[8] Five prominent examples include Lagrangian and Hamiltonian formulations of classical mechanics (Barrett 2019), standard and geometrized formulations of Newtonian gravity theories (Weatherall 2016), Lorentzian manifold and Einstein algebra formulations of general relativity (Rosenstock et al. 2015), Faraday tensor and 4-vector potential formulations of classical electromagnetism (Weatherall 2016), and principal bundle and holonomy formulations of Yang–Mills gauge theories (Rosenstock and Weatherall 2016). Here, then, is a varied class of cases that collectively pose a substantive problem for explanationism.

In each of these cases, I contend, we have intellectual differences without corresponding explanatory differences. Each formulation provides a different understanding than its equivalent counterpart for at least the following simple reason: understanding one does not entail understanding the other (and indeed, showing that they are equivalent requires nontrivial insights). For instance, understanding a phenomenon via Lagrangian mechanics does not entail an understanding of that same phenomenon using Hamiltonian mechanics. Thus, Lagrangian understanding-why differs from Hamiltonian understanding-why, even though both involve grasping the same explanation. The lack of explanatory differences follows from categorical equivalence, which entails that we can inter-translate models of one formulation into models of the other without losing any information.[9] In other words, equivalent formulations possess "the same capacities to represent physical situations" (Rosenstock et al. 2015, 315). On the common ontic conception of explanation assumed here, explanatory information itself is a subset of this physical information, so equivalent formulations *a fortiori* represent the same explanatory information. Thus, whenever one formulation provides an explanation, any equivalent formulation provides the same explanation, preserving everything of explanatory significance—but not necessarily of intellectual significance.

Lagrangian and Hamiltonian mechanics provide a simple but detailed illustration of the foregoing points.[10] These equivalent formulations display two main sources of intellectual differences. First, they differ in how they encode the system's dynamics. The Lagrangian formalism uses a *Lagrangian function* $L(q_i, \dot{q}_i, t)$, encoding the dynamics as a function of time t, generalized coordinates q_i, and generalized velocities $\dot{q}_i$.[11] In the Hamiltonian formalism, we perform a variable change from generalized velocities to generalized momenta p_i, yielding the Hamiltonian $H(q_i, p_i, t)$. Despite encoding the same physical information, the Lagrangian

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[8] For an introduction see Halvorson (2016, 601) and for technical details Weatherall (2016, 2019b).

[9] For defenses of this claim, see Weatherall (2016, 1083, 1087) and Rosenstock et al. (2015, 314).

[10] Technically—within a subclass of models known as the hyper-regular domain—Barrett (2019) shows that the Lagrangian tangent bundle and Hamiltonian cotangent bundle formulations are equivalent. For ease of exposition, I present their more elementary coordinate-based formalisms. For details see Goldstein et al. (2002).

[11] Here, the index *i* runs over {1, 2, ..., n}. The "$\dot{v}$" notation indicates a first derivative with respect to time.

and Hamiltonian organize this information differently, as illustrated below. Secondly, the two formulations represent the dynamical laws of evolution (the equations of motion) in dramatically different ways. Whereas the Lagrangian formulation represents these as a set of n-many *2nd-order* differential equations (the Euler–Lagrange equations), the Hamiltonian formulation represents these same equations of motion as a set of $2n$-many *1st-order* differential equations (Hamilton's equations).[12] By reorganizing the equations of motion in this way, the Hamiltonian formulation treats the generalized coordinates q_i and the generalized momenta p_i more symmetrically. This leads to further intellectual differences in some cases, such as the symmetry argument considered next.

A typical explanandum in mechanics concerns the evolution of a classical system such as a pendulum or spinning top. In systems with symmetry, one generalized coordinate—e.g. q_n—is typically *ignorable*, meaning that it does not occur in the Lagrangian or Hamiltonian.[13] The equations of motion then entail that the corresponding conjugate momentum, p_n, is a conserved quantity, i.e. a constant α. It is here that a dramatic intellectual difference occurs between the formulations. Despite p_n being constant, the corresponding generalized velocity $\dot{q}_n$ need not be. Hence, $\dot{q}_n$ still appears in the Lagrangian as a nontrivial variable. A Lagrangian understanding of the system's evolution thereby still requires considering n-many degrees of freedom, despite having an ignorable coordinate. In contrast, the Hamiltonian formalism enables a genuine reduction in the number of degrees of freedom that need to be considered, resulting in a different understanding. Thanks to changing variables from generalized velocities to generalized momenta, the Hamiltonian depends on the latter but not the former. Hence, we can replace p_n in the Hamiltonian with a constant α, and—with the ignorable coordinate q_n also absent—this eliminates an entire degree of freedom from consideration.[14] As Butterfield remarks, this example "illustrates one of mechanics' grand themes: exploiting a symmetry so as to reduce the number of variables needed to treat a problem" (2006, 43). Although not an explanatory difference, this variable reduction demonstrates a difference in how the same explanatory content is organized. This organizational difference results in a different understanding of the system's evolution. Indeed, these kinds of organizational differences ultimately lead to differences in understanding Noether's first theorem—a foundational result connecting continuous symmetries and conserved quantities (Butterfield 2006).

Thanks to their rigorous mutual inter-translatability, categorically equivalent formulations provide the most precise illustration of my argument. However, at a less rigorous level, theoretically equivalent formulations arise whenever we reformulate a theory while keeping its physical content the same. This motivates including at least some instances of diagrammatic reasoning within the class of theoretically equivalent formulations. Although neglected by the literature on theoretical equivalence, diagrammatic reformulations satisfy the same intuitive criteria: mutual inter-translatability and empirical equivalence. They thereby provide another large class of examples where we can have differences in understanding-why without concomitant explanatory differences. Examples of diagrammatic reformulations include Feynman diagrams in particle and condensed matter physics, graphical approaches to the quantum theory of angular momentum (Brink and Satchler 1968), Penrose–Carter diagrams in space-time theories, graph-theoretic approaches to chemistry (Balaban 1985; Trinajstić

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[12] In both cases, we require $2n$ initial values to solve these equations.

[13] It is easy to show that a generalized coordinate does not appear in the Lagrangian if and only if it does not appear in the Hamiltonian.

[14] Technically, we replace one of Hamilton's equations with a trivial integral for calculating $\dot{q}_n$.

1992), and diagrams for mechanistic reasoning in biology (Abrahamsen and Bechtel 2015).

To illustrate how diagrammatic reasoning can provide intellectual differences, consider Feynman diagrams in particle physics. Here, the explanandum is typically a scattering amplitude for a particular interaction, explained by calculating terms in a perturbation expansion. Without using Feynman diagrams, we can calculate each term up to a desired order in perturbation theory. This provides one way of understanding the scattering amplitude. Alternatively, we can reorganize this same explanatory information using Feynman diagrams, allowing us to express *connectivity properties* of terms in the perturbation expansion. To calculate the scattering amplitude, it suffices to know the connected terms; the disconnected terms do not contribute.[15] Focusing on connectivity thereby makes it unnecessary to consider a vast number of terms in the perturbation expansion—terms that a brute force calculation would show vanish. In this way, Feynman diagrams lead to a different understanding of scattering amplitudes but without introducing any additional explanatory information.[16]

4 A conceptualist account of understanding

I have argued that a variety of mathematical and diagrammatic reformulations provide intellectual differences without associated explanatory differences. Yet, if not from explanatory differences, whence do these intellectual differences arise? To answer this question, I will introduce and defend *conceptualism*, which claims that intellectual differences result from differences in how explanatory information is organized and presented. These organizational differences lead to differences in *what we need to know* to present explanations, leading to differences in understanding-why. I will consider an objection that conceptualism merely describes how reformulations modify explanatory concepts, with no effect on understanding-why. To rebut this objection, I will argue that nontrivial changes in explanatory concepts necessarily lead to differences in understanding-why.

Conceptualism posits a sufficient condition for differences in understanding-why: reformulating an explanation generates an intellectual difference whenever it changes what we *need to know* or *what suffices to know* to present that explanation. For instance, in shifting from Lagrangian mechanics to Hamiltonian mechanics, we learn that we don't need to know how to represent the system and its dynamics using the Lagrangian and the Euler–Lagrange equations. Knowledge of the Hamiltonian and Hamilton's equations suffices. *Mutatis mutandis*, the same can be said for shifting from Hamiltonian mechanics to Lagrangian mechanics, leading again to a difference in understanding. Similarly, reformulating scattering amplitude explanations using Feynman diagrams teaches us that we don't need to know the disconnected terms in the perturbation expansion: knowledge of the connected terms suffices. For convenience, I will refer to these differences in what-we-need-to-know or what-suffices-to-know as *epistemic dependence relations* (EDRs). Conceptualism claims that when equivalent formulations provide different epistemic dependence relations, they manifest intellectual differences.

To rebuff explanationism, these intellectual differences must be genuine differences in *understanding why* empirical phenomena occur. If instead these intellectual differences con-

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[15] A term is connected if there is a path of propagators connecting every pair of source factors and/or vertex factors in the term. For technical background and formal results, see for instance Srednicki (2007, §§8–10) and Lancaster and Blundell (2014, §§16–20, 22, and 24).

[16] de Regt (2017, 251ff) also considers Feynman diagrams to defend his account of understanding. Whereas he focuses on visualization, I focus only on formal features that are independent of human psychology.

cern some other kind of understanding, explanationism is left unscathed. Accordingly, an explanationist might argue that differences in EDRs do not genuinely affect understanding-why. Rather, these differences might merely affect our understanding of the *concepts* used to represent explanations, concepts such as Lagrangians, Hamiltonians, connected diagrams, Lorentzian manifolds, etc.[17] If so, conceptualism would have failed to identify a genuine source of intellectual differences.

Conceptualism agrees with part of this objection: in the first instance, reformulating an explanation changes our understanding *of that explanation*. However, nontrivial changes in understanding an explanation entail differences in understanding-why. Conceptualism reframes this claim as a simple bridge principle:[18]

> *Intellectual bridge principle* (IBP): A nontrivial difference in understanding an explanation of p leads to a different understanding why p.

According to this bridge principle, organizing the same explanatory information differently can lead to a different understanding-why, as we have seen in the case of Lagrangian and Hamiltonian mechanics. Different ways of understanding an explanation are *nontrivial* provided that they are not merely conventional differences in presenting an explanation. Hence, the intellectual bridge principle excludes a large class of *trivial notational variants* from counting as intellectually significant.[19] For instance, uniformly replacing "5" everywhere with "V" in an Arabic numeral system would result in different presentations of many explanations, but these differences would be trivial, rather than intellectually significant. Similarly, recasting an explanation using a left-handed coordinate system rather than a right-handed one would not result in any differences in understanding-why. Although it is difficult to precisely delimit trivial from nontrivial notational variants, my defense of conceptualism requires only the existence of clear cases of nontrivial reformulations, such as those developed in Section 3. In general, conceptualism posits that a difference in epistemic dependence relations is both necessary and sufficient for an intellectually significant difference.[20] Trivial notational variants do not provide different EDRs and hence do not generate intellectual differences.

In response, an explanationist might attempt to reject this bridge principle. However, the IBP follows straightforwardly from the received view of understanding, which explanationism seeks to uphold. Recall that according to the received view, understanding why a phenomenon occurs amounts to grasping an explanation of that phenomenon. Grasping explanations requires that we can represent them, and any way of representing explanations involves concepts. Hence, understanding the relevant explanatory concepts is necessary for understanding-why. Understanding-why is thereby derivative on the way that we have understood this explanation, such as the epistemic dependence relations we have used to present it. Thus, at least some changes in explanatory concepts must lead to concomitant changes in understanding-why. In other words, any account of understanding requires a bridge principle to connect our explanatory concepts with achieving understanding.

With these distinctions in hand, conceptualism straightforwardly identifies the origins of intellectual differences between the equivalent formulations mentioned in Section 3. To take

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[17] I adapt this objection from Khalifa (2017, 138), who develops it as a further argument against Lipton (2009).

[18] de Regt similarly argues that understanding a phenomenon necessarily requires being able to understand a theory (2017, 44). However, I disagree with de Regt that understanding a theory is always pragmatic and contextual.

[19] Grammatically, "intellectually significant" is analogous to "explanatorily significant." It characterizes differences that matter for understanding.

[20] Reasons of space prevent a detailed defense of this claim, which I defend elsewhere.

one example, the Einstein algebra formalism is markedly different from the standard formulation of general relativity. It teaches us that we don't need to know the standard Lorentzian manifold and metric concepts to provide explanations in general relativity. Instead, we can reorganize all of the relevant explanatory information using algebraic notions, as Geroch (1972) has argued. Since this reformulation changes what we need to know to present explanations, it is not a trivial notational variant of the standard formulation. It thereby satisfies the intellectual bridge principle, leading to a different understanding-why for phenomena explained by general relativity.

By itself, conceptualism does not provide a full-fledged account of scientific understanding. Instead, it illuminates an important facet of understanding that has been neglected in the literature. Due to its minimal commitments, conceptualism can be adjoined with existing accounts of understanding, particularly those allied against explanationism. Although compatible with skills-based accounts of understanding, conceptualism does not assume any special role for skills or abilities. The key insight behind my position is that how a theory-formulation organizes explanatory information matters for understanding. Scientific agents perform no more special a role than grasping this organizational structure. For these reasons, my position is not susceptible to the explanationist strategy against skills-based accounts considered in Section 2. Likewise, since conceptualism focuses on how recasting explanations changes understanding, it does not succumb to Khalifa's objections to Lipton's (2009) *understanding without explanation* proposal.

5 An objection against theoretical equivalence

Prima facie, one strategy remains available to an explanationist: they can reject my argument in Section 3 that theoretically equivalent formulations provide the *same* explanation. Instead, they might argue that in such cases, one formulation takes explanatory priority. There are at least two candidate sources of explanatory priority. First, one formulation might be physically privileged. For instance, Curiel (2014) privileges Lagrangian mechanics for allegedly encoding the kinematic constraints of classical systems. Secondly, one formulation might be more fundamental or joint-carving than another. This metaphysical difference would presumably entail a corresponding explanatory difference, wherein the more fundamental formulation provides a better explanation (Sider 2011, 61). Differences in joint-carving or perfectly natural properties would then be part of the explanatory nexus. For instance, North (2009) argues that Hamiltonian mechanics is more fundamental than Lagrangian mechanics.

However, this objection sits uneasily within the broader dialectical strategy of explanationism. Recall from Section 2 that to problematize multifarious accounts of understanding, explanationism adopts a form of explanatory pluralism. Otherwise, it is all too easy to designate some aspects of explanation (e.g. the causal-mechanical ones) as genuinely explanatory while other aspects (such as unification) are seen as mattering for understanding but not explanation. Furthermore, adopting explanatory pluralism seems to require a modicum of ontological pluralism as well (Khalifa 2017, 7). This is because different models of explanation take different ontological features as necessary for providing explanations, as shown in recent debates over causal vs. noncausal explanations (Lange 2017).

Hence, insofar as explanationism requires both explanatory and ontological pluralism, it cannot preclude the interpretation of theoretically equivalent formulations adopted in Section 3. It must allow philosophers to interpret cases of theoretically equivalent formulations as being just that: genuinely equivalent both physically and metaphysically.[21] If explanationists instead adopt a single account of explanation, they will be unable to systematically recast all purported differences in understanding as explanatory differences. The explanationist is thus caught on the horns of a dilemma. Either they renounce explanatory pluralism and thereby fail to systematically deflate skills-based accounts of understanding, or they maintain pluralism and thereby allow that theoretically equivalent formulations provide the same explanation but different understandings.

6 Conclusion

I have argued that theoretically equivalent formulations provide a clear counterexample to explanationism. Whereas explanationism holds that all intellectual differences arise from explanatory differences, equivalent formulations show that some differences in understanding-why do not reduce to explanatory differences. To accommodate these intellectual differences, I have proposed *conceptualism*. Conceptualism argues that understanding-why involves not only the explanatory content that we have understood, but also the way that we have understood it. In particular, it claims that equivalent formulations manifest intellectual differences whenever they provide different *epistemic dependence relations*. These are differences in what we need to know or what suffices to know to provide an explanation. By characterizing how reformulations change understanding, conceptualism addresses complementary lacunae in current accounts of both scientific understanding and theoretical equivalence. In this way, conceptualism supplements existing anti-explanationist accounts of scientific understanding. By adopting conceptualism, these accounts can forestall the challenge from explanationism and genuinely go beyond the epistemology of scientific explanation.

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[21] As Rosenstock et al. note, “it seems far more philosophically interesting to recognize that the world may admit of such different, but equally good, descriptions than to argue about which approach is primary” (2015, 315–16).

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