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Qualification and explanation in the dynamical/geometrical debate

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Abstract

We consider the distinction between 'qualified' and 'unqualified' approaches introduced by Read (2020a) in the context of the dynamical/geometrical debate. We show that one fruitful way in which to understand this distinction is in terms of what one takes the kinematically possible models of a given theory to represent; moreover, we show that the qualified/unqualified distinction is applicable not only to the geometrical approach (which is the case considered by Read (2020a)), but also to the dynamical approach. Finally, having made these points, we connect them to other discussions of representation and of explanation in this corner of the literature.

1 Introduction

Does the geometrical structure of spacetime explain the dynamical behaviour of matter, or *vice versa*? This question lies at the heart of the dynamical/geometrical debate in the foundations of spacetime theories, promulgated by Brown (2005) and Brown and Pooley (2001, 2004), and by now well-established in the literature.[1] Recall that, in this debate, proponents of the 'dynamical' view have it that (in some way or other to be articulated) the dynamics of matter explain why spacetime structure is what it is; by contrast, proponents of the 'geometrical' view have it that (again, in some way

[1] See Brown and Read (2022) for a recent review.

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or other to be articulated) it is the geometrical structure of spacetime which explains why the dynamics of matter are what they are.

In their original writings on this topic, Brown and Pooley (2001, 2004) situated themselves as proponents of the dynamical view, and raised the following charge against their geometrical adversaries:

> [A]s matter of logic alone, if one postulates spacetime structure as a self-standing, autonomous element in one's theory, it need have no constraining role on the form of the laws governing the rest of content of the theory's models. So how is its influence on these laws supposed to work? (Brown and Pooley, 2004, p. 14)

The thought here is that there are plenty of physical theories (some of which are canvassed by Brown and Pooley (2004), and later by e.g. Read et al. (2018)—cf. Read and Menon (2021)) in which (a) one has some putative piece of geometrical structure, alongside (b) some dynamical material fields, but (c) the material fields needn't 'advert' to that spacetime structure. This is supposed to be a problem for self-identifying 'geometrical' authors, for example Maudlin (2012), who writes in the specific context of special relativity that

> the laws of physics take exactly the same coordinate-based form when stated in a coordinate-based language in any Lorentz coordinate system (because *the laws can only advert to the Minkowski geometry*, and it has the same coordinate-based description). (Maudlin, 2012, pp. 117–8, our emphasis)

The reason that such cases seem to be problematic for geometrical views is this: how can it be the case that laws must 'advert' to spacetime geometry, when mismatches of the kind identified by those authors are possible?

But is this charge from Brown and Pooley (2004) really fair? Read (2020a) argues 'no': the charge tracks only a version of the geometrical view which he dubs the 'unqualified geometrical approach' (UGA), according to which, *without further constraints*, a given piece of spacetime structure (Minkowski spacetime, in the case of special relativity) constrains laws to have a certain form—in particular, the geometry constrains the symmetries of the dynamical laws to 'advert' to it. UGA is indeed subject to the 'How is this explanation supposed to work?' charge, given the existence of legitimate mathematical and physical possibilities which appear to be in tension with it.

There are, however, ways other than UGA in which to read the italisised passage in the quote from Maudlin above. One such option is what Read (2020a) dubs the 'qualified geometrical approach' (QGA), according to which when one *antecendently restricts to certain possibilities*—namely, those in which (a) spacetime takes a certain form with certain symmetries (i.e. isometries; we focus here on the case of fixed, non-dynamical spacetimes for simplicity) and (b) material fields are governed by laws with those selfsame symmetries—one can indeed appeal to spacetime structure to explain certain facts about the dynamics of matter—because, of course, the problematic scenarios are excluded *ex hypothesi*. There is some textual evidence that QGA rather than UGA seems to be a better fit for the attitude of Maudlin (2012) himself—consider e.g. passages such as the following:

> The fundamental requirement of a relativistic theory is that the physical laws should be specifiable using only the relativistic space-time geometry. For Special Relativity, this means in particular Minkowski space-time. It is the symmetry of Minkowski space-time that allows us to prove our general result. (Maudlin, 2012, p. 117)

It seems charitable to think that Maudlin's invocation of this 'fundamental requirement' exactly captures his endorsement of (something like) QGA as opposed to UGA, in which case, the 'How is this explanation supposed to work?' charge from Brown and Pooley (2004) seems specious (against Maudlin, at least).

So much for the background. Our purpose in this article is to explore some further, novel aspects of this unqualified/qualified distinction in the foundations of spacetime theories, and also to integrate recent discussions on the dynamical/geometrical approach by in particular (Acuña, 2016, 2025a) and Fletcher (2025) with this distinction. In particular:

1. We formulate the debate in terms of a specific conceptual framework. We characterize spacetime theories as dynamically possible models (DPMs) within a class of kinematically possible models (KPMs). We propose that central questions for the debate can then be tackled by inspecting the geometric objects that define a class of KPMs, and the symmetries of the laws in DPMs within a class of KPMs. Here we take up a suggestion by March (2024) that the dynamical/geometrical debate can be understood fruitfully with the kinematics/dynamics distinction in mind, and show how this allows a clarification of how the qualified/unqualified distinction applies to both sides in the dispute.
2. Read (2020a) has shown that in the geometrical view a distinction can be drawn between an unqualified and a qualified approach. Using the framework of KPMs and DPMs, we show that this distinction applies to dynamicism as well. That is, there also is a distinction to be drawn between 'qualified' and 'unqualified' dynamical approaches.
3. We show that a qualified conception of geometrical and dynamical explanations can be adopted, while remaining non-committal about the dynamical/geometrical approaches themselves. This turns out to be a clarifying way in which to characterize a third stance in the debate proposed by Acuña (2016, 2025a): the 'counterparts view'.
4. We connect the distinction between unqualified and qualified approaches with a thesis of 'geometrical representation by stipulation' which one can extract from Fletcher (2025). In particular, we propose that this thesis facilitates an understanding of how the conceptual analysis and development of spacetime theories can converge to a match between dynamical and spacetime symmetries. This process of convergence, in turn, seems to vindicate qualified stances over unqualified ones.

5. Having done all of the above work, we shore up and illustrate some outstanding issues regarding explanation in the debate between dynamical and geometrical approaches, in dialogue with Read (2020b). In particular, we distinguish three different senses of explanation involved in the debate: (i) an arrow of explanation joining dynamical and spacetime symmetries, (ii) dynamical and geometrical explanations of spatiotemporal phenomena, and (iii) a sense of explanation running from phenomena to features of a spacetime theory. In the context of these three levels of explanation, our framing of the debate in terms of KPMs and DPMs allows for a deeper understanding and an evaluative comparison of the existing approaches.

Here's the plan. In §2, we show how to understand the qualified/unqualified distinction in terms of the kinematics/dynamics distinction. In §3, we show that a qualified/unqualified distinction is possible within the context of the dynamical approach; as such, the qualified/unqualified distinction turns out to be orthogonal to the dynamical/geometrical distinction. In §4, we describe how the 'counterparts view' of Acuña (2025a) fits into this setting. In §5, we consider in this context the above-mentioned theses regarding the representation of geometry in one's physical theories. In §6, we turn to explanation, and in §7 we seek to illustrate many of the themes and issues raised in this article in the particular context of the famous thought experiment of the rockets due to Bell (2004). In §8 we wrap up.

2 Qualification and the kinematics/dynamics distinction

In the foundations of spacetime theories literature, it's pretty widespread to characterize spacetime theories by first (a) specifying their 'kinematically possible models' (KPMs), which are tuples of geometric objects out of which the theories are constructed, and subsequently (b) restricting to their 'dynamically possible models' (DPMs), which are those KPMs in which the geometric objects specified therein are constrained to satisfy certain dynamical equations.[2] Given a class of KPMs, there is of course a range of different choices of dynamics that determine different classes of DPMs, and in turn different such choices determine different theories with the same kinematical structure. Thus, thinking in terms of KPMs and DPMs invites a stratified picture, whereby the DPMs are nested inside the KPMs, as in Fig. 1.

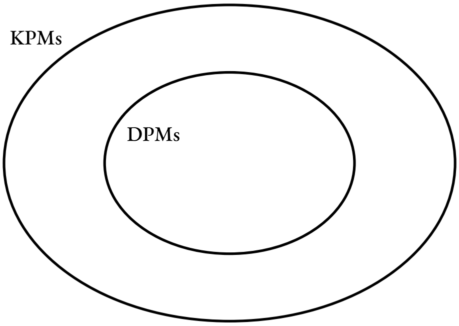
To give one simple example: the KPMs of a massive Klein–Gordon theory are triples $\langle M, \eta_{ab}, \varphi \rangle$ where M is a differentiable manifold, η_{ab} is a fixed Minkowski metric field on M, and φ is a real scalar field on M; the DPMs are then given by the massive Klein–Gordon equation,

$$\eta_{ab}\nabla^a\nabla^b\varphi - m\varphi = 0, \tag{1}$$

where $m \in \mathbb{R}$.

[2] Here, we'll set aside some delicate issues, e.g. that spinors aren't geometric objects—for more on that topic, see Pitts (2012).

Fig. 1 As defined, the dynamically possible models (DPMs) of a theory are nested inside its kinematically possible models (KPMs)



Our first contention in this article is that one can think about the differences between UGA and QGA in terms of the framework of KPMs and DPMs. Consider some theory—the Klein–Gordon theory given above would serve as an example—in which symmetries of the dynamical laws (in the example above, Eq. 1) coincide with the symmetries (i.e. isometries) of the spacetime structure (in the example above, η_{ab}). In the DPMs of the theory, there is therefore accord between dynamical and spacetime symmetries. Evidently, however, this accord does not extend to all the KPMs determined by the geometric objects, for there the dynamics are unspecified, and in principle it is possible that dynamical symmetries come apart from spacetime symmetries. (For example, in the KPMs of the above theory, there will be DPMs in which the fields satisfy the *massless* Klein–Gordon equation,

$$\eta_{ab}\nabla^a\nabla^b\varphi = 0, \tag{2}$$

which also has conformal symmetries.)

Let's call a theory 'well-tuned' just in case its dynamical symmetries coincide with its spacetime symmetries in its DPMs. In other words, a theory is well-tuned just when it satisfies in its DPMs the famous symmetry principles of Earman (1989, p. 46), SP1 ('any dynamical symmetry is a spacetime symmetry') and SP2 ('any spacetime symmetry is a dynamical symmetry'). Moreover, for the sake of clarity we'll restrict to well-tuned theories in our discussions over the next few sections, although we will relax the assumption in §5.

For well-tuned theories, then: by considering the question of whether spacetime can explain the dynamics of matter *after restricting to the well-tuned DPMs* within a class of KPMs determined by certain geometric objects, one is automatically embracing a qualified approach (e.g. QGA for the geometrical approach); worries about symmetry mismatches in the KPMs cut no ice against such qualified views. When considering *the entire space of KPMs* and making assertions that there cannot be symmetry mismatches *here* (or, better, in the possible worlds which these KPMs purport to represent), one is working within the framework of an unqualified approach (e.g. UGA for the geometrical approach), and is *ipso facto* leaving oneself open to the problem cases pointed to by proponents of the dynamical approach such as Brown and Pooley (2004), as already discussed above.

All of this, we take it, is consistent with and substantiates a suggestion recently made by March (2024, fn. 20), that the kinematics/dynamics distinction can be brought to bear in fruitful ways upon the dynamical/geometrical debate. But just to say a little more about the qualified/unqualified distinction here: according to qualified approaches (e.g. QGA), one could say that the DPMs of a theory represent physically possible worlds (according to that theory, of course), while models with different dynamics (including those with symmetries that don't match the isometries) within the same class of KPMs represent merely metaphysically possible worlds. Now, explanatory questions are to be raised and answered exclusively in the content of the physically possible worlds, where (for well-tuned theories) spacetime symmetries and dynamical symmetries coincide. However and by contrast, according to proponents of UGA, arguments might be mustered to the effect that spacetime–dynamics symmetry mismatches—i.e., violations of the symmetry principles of Earman (1989)—are metaphysically or logically impossible. Thus, while they might be legitimate pieces of mathematics, models with untuned dynamics don't represent metaphysically possible worlds in which Earman's principles are violated. Thus, the physically possible worlds represented by the theory via its DPMs observe such principles, and the violation thereof is in fact a metaphysical or logical impossibility. If such arguments are compelling, then advocates of unqualified approaches needn't be worried by cases of spacetime–dynamics symmetry mismatches in the KPMs of the theory; the problem, of course (and to repeat), is that *prima facie* the claim seems to be subject to the 'How is this supposed to work?' charge.[3]

3 Qualified dynamical approaches

Now that we've seen that it's quite natural to associate qualified approaches with an exclusive focus on the DPMs of a given theory (as opposed to its KPMs) when it comes to explanatory questions regarding the relationship between spacetime and material dynamics, it's also natural to ask whether the notion of 'qualification' in the dynamical/geometrical debate can in fact be liberated from the geometrical perspective in particular. In other words, it's natural to ask this: is there any such view as a qualified *dynamical* approach?

We think that the answer to this question is 'yes'. The idea is this. Just as UGA has it that a piece of geometrical structure *per se* constrains the dynamical laws to 'advert' to it, so too would an unqualified dynamical approach (henceforth 'UDA') have it that a set of dynamical laws (with certain dynamical symmetries) *per se* constrains the spacetime geometry to be what it is. To pick up our discussion from the previous section: one could say that, on UGA, spacetime–dynamics symmetry mis-

[3] To be completely clear, the idea here is not that proponents of unqualified approaches must invoke these metaphysical/logical constraints in order to *avoid* the 'How is this supposed to work?' charge. Rather, the idea is that unqualified approaches invoke these strong metaphysical/logical constraints that models with untuned dynamics do not represent *bona fide* possible worlds (because, for unqualified approaches, mismatches between spacetime and dynamical symmetries are impossible), but absent further details it is not clear where these constraints come from, or why they obtain. As such, *it is precisely the invocation of such constraints which is subject to the 'How is this supposed to work?' charge*. Existing conceptually legitimate spacetime theories such that their DPMs are untuned make it dubious that symmetry mismatches can be rendered logically flawed (let alone impossible), or that untuned DPMs cannot represent metaphysically possible worlds. Our thanks to an anonymous reviewer for pushing us to be clear here.

Table 1 The dynamical/geometrical debate is orthogonal to the qualified/unqualified distinction

	Geometrical approach	Dynamical approach
Mismatches metaphysically impossible	UGA	UDA
Mismatches physically impossible but metaphysically possible	QGA	QDA

matches are metaphysically or logically impossible, for geometry *always* constrains the laws for material fields to take a certain form (with certain symmetries). On the other hand, for QGA, spacetime–dynamics symmetry mismatches are (at least in well-tuned theories—which recall are our exclusive focus here) physically impossible but metaphysically possible, for at least in the DPMs spacetime structure can be used to explain facts about the dynamics, the form of the laws, etc.[4]

Similar ideas carry over to qualified and unqualified versions of the dynamical approach (in what follows, call the qualified version of the dynamical approach 'QDA'), but with the arrows of explanation reversed. One can say that, on UDA, spacetime–dynamics symmetry mismatches are metaphysically impossible, for dynamical laws (and their symmetries) always constrain spacetime geometry to take a certain form. On the other hand, for QDA, spacetime–dynamics symmetry mismatches are (at least in well-tuned theories) physically impossible but metaphysically possible, and at least in the DPMs dynamical laws (and their symmetries) can be used to explain certain facts about the spacetime geometry. Given this, then, it turns out that there are in fact *four* distinct positions here, and that the qualified/unqualified distinction is *orthogonal* to the dynamical/geometrical distinction. We have summarised these four positions in Table 1.

Having formulated the dynamical/geometrical debate in terms of KPMs and DPMs, and having identified QDA as yet another possible stance which one could hold in this debate, we can now further characterise the differences between QGA and QDA. One could say that that while spacetime symmetries and dynamical symmetries agree in all physically possible worlds for a well-tuned theory, and it is these worlds (represented by the DPMs of the theory under consideration) which are of exclusive interest to proponents of qualified views, QGA and QDA both nevertheless recognise *hyperintensional* explanatory asymmetries in these worlds—explanatory asymmetries which cut finer than intensional differences in this set of worlds (see e.g. Berto and Nolan, 2023). In particular, the QGAist thinks that the explanatory arrow runs from geometry to dynamics in these worlds, whereas for the QDAist the opposite is true. We will discuss further below the form that these explanatory differences might take.

[4] On QGA, an anonymous reviewer has put to us the following concern: if on this view theories with mismatches between spacetime symmetries and dynamical symmetries represent metaphysically possible worlds, then in what sense can spacetime structure be said to constrain the form of the dynamics? There are a few answers which one can give to this question: one would be to point to the fact that, *in the DPMs* of the theory, spacetime structure is coupled to material fields, and in this sense constrains it (see Read, 2020a). Another thing which one could say here is that, even granting that some 'explanation by constraint' narrative is lacking, QGAists might in the DPMs still be able to avail themselves of other notions of geometrical explanation—see §6 below. And in any case, as a matter of exegesis, it still seems to us (following Read, 2020a) that QGA makes better sense of some extant geometrical approaches (e.g. Maudlin, 2012) than does UGA.

Of course, however, it’s all well and good to identify new positions in logical space—but what one would really like to do is to show that these positions occupied by flesh-and-blood actors in the debates. In fact, we think that this is indeed the case. For example, one way of reading Brown (2005, ch. 8), at least in the context of special relativity (and other theories where the spacetime structure is fixed and non-dynamical—see Brown and Read, 2022), is that it is metaphysically impossible for spacetime symmetries to come apart from dynamical symmetries, because the former are *always* explained by the latter; spacetime is only a *dispensable condification* of the dynamical symmetries. If this is correct, then Brown in the context of special relativity can be taken to endorse UDA.

On the other hand, because Brown (2005, ch. 9) maintains that the metric field of general relativity is on the same ontological footing as material fields, that the coupling between metric and material fields is contingent, and no longer embraces the above-described ontological reduction thesis in this setting, he is willing to countenance spacetime–dynamics symmetry mismatches, and so better qualifies as a proponent of QDA when it comes to general relativity.[5] One can see this clearly in the fact that Brown regards the accord of spacetime and dynamical symmetries in the context of general relativity as a contingent fact—what Read et al. (2018) dub a ‘miracle’—and explicitly presents (supposed) problem cases in which (local) spacetime and dynamical symmetries come apart in general relativity (see again Read et al., 2018).

Given his claim that the connection between spacetime and dynamical symmetries is analytic, one could also perhaps read (Myrvold, 2019) as a proponent of UDA; we will in fact have more to say about Myrvold’s views, especially as compared with those of Acuña (2016, 2025a), in the next section.

4 The counterparts view

Taking stock, what we’ve seen so far is that: (i) the kinematics/dynamics distinction is a helpful way of understanding the distinction between qualified/unqualified approaches (§2), and (ii) one can liberate the qualified/unqualified distinction from geometricism in particular, to see that this distinction applies also within the context of the dynamical approach (§3). Now we spell out how the ‘counterparts view’ of the explanatory relation between spacetime and geometry, espoused primarily by Acuña (2016, 2025a, 2025b), enters this way of thinking.[6]

According to the counterparts view, in well-tuned cases like special relativity, spacetime geometry and dynamical symmetries are ‘two sides of the same coin’ (Acuña, 2016), and neither *per se* has explanatory priority over the other. It is this explanatory non-priority thesis which we would like to focus on in this section, for it

[5] All of this presupposes that it makes sense to speak of spacetime symmetries and dynamical symmetries in the context of general relativity—Read et al. (2018) propose to do this locally, but this suggestion has faced reasonable pushback and calls for clarification from Fletcher (2020); Fletcher and Weatherall (2023a, 2023b); Weatherall (2020). We won’t go further into any of these issues here.

[6] To be clear, this ‘counterparts view’ obviously has nothing to do with counterpart theory in the sense of Lewisian modal metaphysics.

also seems to us that such a position fits naturally into the framework which we have developed above.

To be more specific, our thought—developing on from Acuña (2025a) in particular, where connections between the counterparts view and the qualified/unqualified distinction are suggested *en passant*—would be this. The counterparts view is perhaps best regarded as being a certain kind of qualified view: *when* dynamical symmetries coincide with spacetime symmetries, one can consider explanations which run from geometry to dynamics, and *vice versa*. One can treat such explanations in an entirely pragmatic manner, and does not have to commit (*per* either the dynamicist or geometricist) to the explanatory arrows running *exclusively* in one direction or the other.[7] When dynamical symmetries do not coincide with spacetime symmetries, however, it is not so clear that this explanatory bidirectionality is available—the explanations seem 'partial', in the sense of Read (2020a, §5.2.2).[8]

Moving on: another author who has written on the dynamical/geometrical debate in recent times, and who is often regarded as being a kindred spirit of Acuña (2016)—perhaps (one might think) another proponent of the counterparts view—is Myrvold (2019). Myrvold has it that Earman's symmetry principles—recall again, the coincidence of dynamical and spacetime symmetries—are *analytic*, in the sense that they encode connections between spacetime symmetries and dynamical symmetries which obtain *in virtue of meaning*. But if this analyticity thesis holds up, then it is hard to see how Myrvold could ever envisage spacetime symmetries coming apart from dynamical symmetries *in any metaphysically possible world*, and as such it makes sense to identify him as a proponent of an unqualified approach.

According to Myrvold's view, untuned DPMs are either meaningless, or *a priori* semantically flawed. This is a stronger thesis than the counterpart/pragmatic stance of Acuña (2016, 2025a, 2025b), which is a *qualified* view: one can use spacetime structure to explain facts about the dynamics and *vice versa* in the physically possible worlds according to a well-tuned theory as represented by its DPMs, but this isn't to deny that spacetime symmetries might come apart from dynamical symmetries in other (metaphysically) possible worlds. As a result of this, what we see then is that the qualified/unqualified distinction affords us the means to articulate ways in which one might distinguish between views—namely and to repeat, those of Myrvold (2019) and Acuña (2016)—which might otherwise be assimilated in the literature.[9,10]

[7] Note that there is a case to be made that Weatherall (2017, p. 157) also espouses something like the counterparts view, since he writes "And so, geometry constrains dynamics, but so too dynamics constrains geometry. The inferences—and the explanations—go in both directions." For further discussion of this, see Acuña (2025a).

[8] Anyhow, the counterparts view identifies explanatory connections between spacetime structure and dynamics that go beyond (mis)matches between symmetries. For example, in Weatherall's analysis of the Geroch–Jang theorem, the principle that free bodies follow timelike geodesics can be explained from geometric and dynamical assumptions that don't involve considerations about symmetries. See Weatherall (2017) and Acuña (2025a).

[9] Our suggestion here draws a sharper line between Myrvold (2019) and Acuña (2016) than does e.g. Acuña (2025a, §5.3).

[10] Another author who leverages the KPM/DPM distinction in order to critically assess approaches which (at least *prima facie*) understand the connection between spacetime symmetries and dynamical symmetries to be analytic (i.e., the approaches of Acuña, 2016 and Myrvold, 2019) is Sus (2019, 2023). Sus argues

Finally on this topic: in response to the above-described 'mismatch' problem cases for unqualified approaches (invoked, as we've seen, by Brown and Pooley (2004) as part of their critique of UGA), Myrvold (2019, §8) suggests that there are not *really* mismatches in such cases, when one attends to the 'real' dynamics associated with the spatiotemporal structure in the KPMs (to be clear: Myrvold himself does not deploy the KPM/DPM terminology). To which we respond: while it's true that invoking an analytic spacetime–dynamics connection serves to blunt the mystery as to how this coincidence could arise, it's worth tempering this with a degree of caution. The reason for this is that if spacetime symmetries *just are* dynamical symmetries, then the former cease to have any independently interesting and valuable role to play in theorising about spacetime theories.[11] Besides, Myrvold's response to untuned cases seems not to be applicable to the case of Lorentz's ether theory (see §7). In addition, this 'analytic connection' view stands in contrast (and tension) with another outlook on the spacetime–dynamics connection—one which we'll now proceed to explore.

5 Representational stipulation and iteration

So far, we've explored the qualified/unqualified distinction in the context of well-tuned theories—i.e., theories whose spacetime symmetries and dynamical symmetries coincide in their DPMs. What we'd like to consider in this section is what happens when this assumption is relaxed, and (more specifically) how one might arrive at a well-tuned theory even when beginning from a starting point whereby one does not have such a theory.

Let's take for granted, in the spirit of proposals made recently by Fletcher (2025), that whenever one is presented with the models of some spacetime theory, one has to make an initial *stipulation* as to what in those models represents spacetime, i.e. what represents intervals of distances and times. We can schematise this as follows (now using the notation of Read (2023a, ch. 3) deployed in the context of a discussion of Belot, 2011): if the KPMs of the theory in question are given by tuples $\langle M, O_1, \ldots, O_n \rangle$ where as usual *M* is a differentiable manifold and the O_i are geometric object fields on *M*, and dynamics are given by some differential equations for the O_i, then one proceeds in the interpretation of this theory by stipulating that one of these objects (or combination thereof—but for simplicity we'll set aside that case) represents (spacetime) geometry, and accordingly marks it with a superscript 'G', so

that the coincidence of spacetime and dynamical symmetries should be understood not as an analytic principle but rather as a constitutive one (in roughly a Kantian sense). Now, since he conceives constitutive principles from which the matching of symmetries results as *relativized a priori*, the contingency of such principles seems to imply a qualified stance. Sus' approach also seems to converge with the counterparts view in that there is no hierarchy between dynamical and spacetime symmetries. However, the counterparts view explicitly rejects a constitutive foundation for the connection between dynamical and spacetime symmetries (Acuña, 2025a), and adopts a pragmatic conception of the explanatory connections between them (more about this below).

[11] Cf. the critiques of 'epistemic' approaches to symmetries presented by Read and Møller-Nielsen (2020b), who worry that by saying (as does e.g. Dasgupta, 2016) that symmetries *just are* those maps from models of a theory to its models which preserve empirical content, one ceases to afford the notion of a symmetry transformation any independently interesting role to play in theorising about physical theories.

writing the KPMs $\langle M, O_1, \ldots, O_i^G, \ldots, O_n \rangle$. One can *then* inquire as to the coincidence (or otherwise) of the symmetries of O_i^G and of the dynamics—one can inquire, in other words, as to whether the theory is well-tuned, in the sense in which we have been using this term in this paper.[12]

Given that the initial geometrical stipulation was arbitrary, there is no reason in general to think that this will be the case—the initial geometrical stipulation might well be an 'educated guess', but also might be one which in fact violates Earman's symmetry principles.[13] However, as one becomes better acquainted with the theory, one might come to identify in it what physicists call 'hidden symmetries'—symmetries of the dynamics which were not initially obvious or well-appreciated—and in turn come to *recalibrate* one's initial geometrical stipulation in order to bring it into line with (what one now understands to be) the dynamical symmetries of the theory.[14]

Here is a concrete example. Take the Trautman gauge symmetry of Newtonian gravity set in Galilean spacetime: simultaneously redefining the affine connection and gravitational field of this theory in specific and compensating ways yields a distinct spacetime model which is nevertheless empirically equivalent to the original model. Plausibly, prior to the work of Trautman (1965), this transformation would have counted as hidden—even though, naturally, it does not now so count! One can indeed take more recent work on the interpretation of Newtonian gravity in light of Trautman gauge symmetry—e.g. (Knox, 2014; Read and Møller-Nielsen, 2020a)—to exactly offer and invite an updating of what we take the geometrical structure of Newtonian physics to be (in this case, to invite us to move to the framework of Newton–Cartan spacetimes) in light of spacetime–dynamics symmetry mismatches in one's original interpretation of the theory.

Ultimately, the hope is that one will eventually converge, via a process of reflective equilibrium, to an understanding of the geometrical structure of a given theory which renders it well-tuned, in the sense (to repeat) that Earman's principles are satisfied in its DPMs. This narrative we take to be consonant with the arguments made regarding 'hermeneutic circle reasoning' in the presence of symmetries by Read and Møller-Nielsen (2020b) (although in the latter case the focus was updating one's understanding of the empirical content of a theory—rather than its spacetime symmetries—in an iterative process). Now, although we have simply by stipulation restricted to the case of well-tuned theories in the preceding sections of this article, it is interesting (in our view) to see that this restriction can be relaxed, and that a plausible account as to how nevertheless we might equilibrate to such an interpretation of spacetime theories (thereby making the initial stipulation a more reasonable one) is available. Although

[12] Depending upon which such O_i is selected as being 'geometrical', it might be difficult to make sense of its symmetries. For example, how to make sense of the symmetries of a dynamical metric field? (Cf. footnote 5.) And if this object so selected is in fact *not* any kind of metric field, then one cannot cash out its symmetries in terms of its isometries, but will have to recourse to some other notion, and it might not be obvious what that should be.

[13] Of course, this is not possible on e.g. the approach of Myrvold (2019) discussed above, which to our minds raises questions about that approach and how it might be reconciled with the outlook on the representation of geometry in physical theories being considered here, and by Fletcher (2025).

[14] The notion of a hidden symmetry was discussed in the philosophical literature only surprisingly recently, by Bielińska and Jacobs (2024); for further discussion of the notion, see Read (2025).

well-tunedness as a goal has epistemic and pragmatic appeal, it is salutary and cautious not to promote it to an *a priori* principle in spacetime theorising.[15]

What we offer here, therefore, is an account of why spacetime and dynamical symmetries coincide in the DPMs of a given theory of which both qualified accounts—i.e., both QGA and QDA—appear to be able to avail themselves. (Unqualified approaches seem not to need to deploy such 'hermeneutic circle' reasoning, as these approaches make—as we have seen—the coincidence of spacetime and dynamical symmetries a matter of metaphysical necessity.) That is, all three of QGA, QDA, and the counterparts view can in principle appeal to reasoning such as this in order to account for how spacetime theories (usually) come to be well-tuned. Now, this account of well-tuning does not address other explanatory questions in this regard: for example, one might still desire an account of why the dynamics in the DPMs are as they are by appeal to some more fundamental theory of physics: see Read (2019). Moreover, although the qualified approaches (including the counterparts view) can in principle agree on *how* spacetime theories converge to well-tuning, they still disagree about explanatory relations between spacetime structure and dynamics in well-tuned theories. In other words, precisely because of the qualification, statements in these views about explanations from dynamics to spacetime structure and/or from spacetime structure to dynamics do *not* involve claims about constraining by necessity from dynamics to spacetime structure or from spacetime structure to dynamics. Nevertheless, as we will see in the next section, different prior conceptual stances about the nature of explanation and/or about the ontology of spacetime connect, in well-tuned scenarios, to different stances about explanatory connections (of some kind) between spacetime structure and dynamics.

6 Explanation

So far in this article, we've teased apart the qualified/unqualified distinction from the dynamical/geometrical distinction, and have also seen how the 'counterparts view' of Acuña (2025a) is accommodated quite naturally in this framework. What we have not yet done, however, is say much about different notions of explanation which might be in play—in this section we turn to these matters.[16]

A nuanced understanding of the issue of the connection between geometric structure and dynamics in spacetime theories benefits from fine-graining different explanatory claims. First, of course, we have the question that is central to the debate: the direction of the arrow of explanation between spacetime structure and the form of dynamical laws. This level of explanation occurs, so to speak, *within the theory*. A second kind of explanatory arrow runs *from theory to phenomena*. Here geometricists and dynamicists diverge with respect to what features of the theory—spacetime

[15] Perhaps having a well-tuned theory in this sense is not the be-all-and-end-all. For example, the ether theory was not well-tuned (dynamics were Lorentz invariant but the spacetime had a preferred frame), yet for much of the 19th century was taken to have various explanatory merits. (For more on the ether theory, see e.g. Acuña, 2014; Bradley, 2021; Janssen, 1995; Janssen, 2002b.)

[16] This section can, therefore, be understood as picking up on themes from Read (2020b).

structure or dynamical laws—bear the epistemic load in the explanation of the behaviour of physical systems. Third—the least explored level—there is the possibility of an explanatory arrow which runs *from empirical regularities* exhibited by phenomena *to certain aspects of a spacetime theory*.

We have already characterised the different stances in the debate with respect to the first level of explanation, but we now want to make the connection with the second, as well as to add some evaluative remarks. The UGAist asserts that the spacetime structure determined by the geometric objects postulated in the KPMs of a given theory enforces that the DPMs be well-tuned, and that lack of well-tunedness is a metaphysical or logical impossibility. When it comes to the second level of explanation (i.e., that from theory to phenomena), however, the UGAist might go further, averring that explanations of the physical behaviour of material systems (e.g., rods and clocks) essentially and primordially rely on the corresponding geometric structure. For example, *per* the UGA-style reading of the passage from Maudlin which we quoted in §1, the UGAist might state that it is the structure of Minkowski spacetime that explains Lorentz contraction and time dilation of rods and clocks (respectively). Dynamical details can be added into those explanations, but in any case it is the geometry of the theory that explains the form of the dynamics; dynamical explanations of (in this case) characteristic special relativistic effects are epistemically parasitic on the geometric explanation.

The UDAist inverts the arrow of explanation in the first level, and inverts the epistemic hierarchy in the second one. As we saw, in special relativity this approach (at least as we find it in Brown, 2005, ch. 8) states that Minkowskian geometrical structure is but a dispensable codification of Poincarè invariant dynamical laws. Accordingly, in the second of level of explanation from theory to phenomena, the UDAist states that explanations of Lorentz contraction and time dilation are given by a purely dynamical account. Descriptions and explanations of these phenomena in terms of Minkowski structure are parasitic on the dynamical ones, and ultimately reducible to them—hence UDA's claim (see Brown, 2005) that moving rods contract and moving clocks run slow because of how they are made, not because of the spacetime structure into which they are embedded.

Despite the opposite direction of the explanatory arrow in the first level and the inverted epistemic hierarchy in the second, UGA and UDA agree that well-tuning is not a contingent matter: as we have explained, symmetry mismatches are impossible on both unqualified views. For unqualified approaches to be defensible, well-tuning must be a matter of metaphysical, logical or semantic necessity, but as we have seen it is rather obscure how this can be so.

Our description of the qualified versions of dynamicism and geometricism in terms of DPMs in a class of KPMs clarifies that they are not affected by the problem cases and 'How is this explanation supposed to work?' charges which we have discussed in the previous sections of this article. Both QGA and QDA consider well-tuning in the DPMs to be a contingent feature in spacetime theories. Both stances still claim that there is an arrow with a preferred direction joining dynamics and spacetime structure in the first level of explanation (and of course the direction of this arrow will be reversed depending upon whether one is a QGAist or QDAist), and therefore propose an epistemic hierarchy in the second level of explanation from theory to phenomena (which, again, will differ depending on which of the two qualified positions is endorsed). But, evidently, they are inoculated against the specific problems faced by unqualified approaches.

Apart from an assessment of viability and cogency, applying the unqualified/qualified distinction to both sides of the debate also allows for a clarification as to how UGA and UDA on the one hand and QGA and QDA on the other differently conceive of explanatory connections in the first two levels of explanation which we have just distinguished. As we just mentioned, in the context of special relativity, Brown's proposal seems to be an instance of UDA: Poincaré invariance of dynamical laws constrains and explains why spacetime structure—which is only a dispensible codification of Poincaré invariant dynamics—is given by Minkowski geometry. In UGA, the converse thesis is the case: Minkowski geometry somehow constrains dynamical laws to take a Poincaré invariant form. That is, both in UDA and in UGA we get an explanation of well-tunedness of DPMs by constraint, but with the direction of the arrow of explanation inverted. In turn, this explanation of well-tunedness by constraint implies an epistemic hierarchy in the second level of explanation (where the hierarchical order depends on the direction of the arrow postulated in the first level).

In the case of general relativity, as we have already argued, Brown (2005, ch. 9) better qualifies as a supporter of QDA: he doesn't intend to reduce the metric field to dynamics, and claims that the metric field acquires its spatiotemporal significance from the contingent dynamical assumptions such as 'minimal coupling'. As a consequence, *the match itself* between dynamical and spacetime symmetries (cf. footnote 5) doesn't get explained by constraint, nor explained at all—so it's described as a 'miracle' (see Read et al., 2018). However, *given the contingent match between symmetries*, Brown asserts that dynamics explains spacetime structure in the sense that the metric field acquires its spatiotemporal significance from dynamical assumptions. As the reader can notice, QGA also renders the match between symmetries as 'miraculous' in the sense described, while still invoking some reason (other than necessary constraint) to single out spacetime structure as explanatory with respect to dynamics.

The difference between Brown's dynamicism in special and general relativity illustrates that qualification is responsible for the fact that the match between symmetries cannot be explained as a matter of constraint. That is, in qualified approaches—both geometrical and dynamical—explanatory connections at the first level can't be established by arguments involving (metaphysical, logical, or semantic) necessity. Thus, in the qualified approaches, the grounds for a preferred direction for the arrow in the first level, and for a specific epistemic hierarchy of explanations in the second level, must refer to other kinds of considerations.

For example, a prior commitment to causal explanations in the spirit of Salmon (1984), or to 'constructive explanations' in the sense of appealing 'constructive theories' (see Read, 2020b),[17] might naturally lead to a preference for dynamical explanations of phenomena, and thereby to QDA. On the other hand, a prior commitment to explanation in the unificationist spirit of Kitcher (1989), like the 'structural explanations' of Dorato and Felline (2010) or the 'geometric explanations' of Nerlich (2010),

[17] For more on Einstein's 1919 distinction between theories of principle and constructive theories, see Howard and Giovanelli (2025) and Brown (2005).

might lead naturally to a preference for geometrical explanations of phenomena, and thereby to QGA. Finally, prior commitments in the epistemology of explanation might also be connected to stances regarding the ontology of spacetime: relationalists would naturally tend to adopt QDA, whereas substantivalists might opt for QGA.[18]

We can illustrate this point using the geometrical approach to special relativity of Janssen (2002a, 2009). Janssen recognizes that whereas Einstein's theory is well-tuned, its empirically equivalent rival, Lorentz's ether theory, isn't (he doesn't use the framework of KPMs and DPMs, though: see Janssen (2009, pp. 47-48)). Thus, Janssen's view is an instance of QGA. Now, he argues that Einstein's theory is superior to Lorentz's because in the former effects like time-dilation, length-contraction, the velocity-dependence of mass, the Fresnel drag-coefficient, and the torques on a moving capacitor observed in the Trouton–Noble experiment, are all explained by a *common origin inference* (COI)—a special case of inference to the best explanation—in which the explanatory common origin of the *explananda* is Minkowski geometry. That is, based on the epistemic value of COI explanations, Janssen identifies a sense in which, *in the well-tuned case* of special relativity, spacetime structure explains dynamics. However, since he recognizes an untuned theory as a legitimate (though inferior) rival, the explanation captured by the COI can't involve a necessary constraint from geometric structure to dynamical symmetries.[19]

Summing up, we have that: (i) UGA and UDA are unviable for similar reasons, and (ii) QGA and QDA are legitimate stances, but claims of a preferred arrow of explanation in the first level, and claims of a hierarchy between dynamical and geometric explanations in the second level, must be grounded on ulterior commitments (e.g., about explanation or spacetime ontology). The counterparts view of Acuña (2014, 2025a, 2025b), on the other hand, adopts a qualified and pragmatic conception of explanation. In this approach, claims of a preferred direction for the arrow in the first level of explanation, or a preference for dynamical over geometric explanations of the phenomena, are always indexed to a certain epistemic context: it all depends on the specific why-questions we address. (Obviously, this is in the spirit of the pragmatic approach to explanation famously offered by van Fraassen (1980).) Thus, a general commitment to a specific form of scientific explanation is discarded, so although the counterparts view adopts qualified explanations, it opposes both QGA and QDA.[20]

As indicated above, the third (and least explored) stripe of explanation runs from phenomena to theory, rather than the other way around. Here, we don't mean a naïve inductivist conception of scientific theorizing; rather, the idea is that starting out from conceptualizing phenomenological regularities in a certain way, general theoretical principles of a spacetime theory can be derived via conceptual–deductive analysis. One obvious example of this is given by the Ehlers–Pirani–Schild 'constructive axiomatization' of the kinematic structure of general relativity, on which see Adlam et

[18] We take all of these points to be in the spirit of, and consistent with, Acuña (2016); Read (2020b).

[19] Here we assume that if one accepts that an untuned theory with Newtonian spacetime symmetries and Lorentz invariant laws in its DPMs (like Lorentz's) represents metaphysically possible worlds, by the same token one should accept that, in principle, a theory with Minkowski spacetime symmetries and untuned DPMs can also represent metaphysically possible worlds.

[20] The adoption of the counterparts view might motivate the adoption of a certain conception of the ontology of spacetime, but that's for another occasion.

al. (2025). From axioms that encode some phenomenological regularities exhibited by light rays and freely-falling particles, expressed in highly economical geometric principles, Ehlers et al. (2012) derive the kinematical structure of general relativity. As Adlam et al. (2025) explain, this approach is congenial to QDA as we describe it here. *A fortiori*, the counterparts view, in the appropriate pragmatic context of explanation, can recognize an epistemic value in the constructive axiomatics approach.[21] As another example, we suggest that Einstein's original approach in the formulation of special relativity (Einstein, 1905) can be understood as an instance of explanation of aspects of a spacetime theory starting out from empirical regularities. Einstein's two postulates (plus suitable assumptions), which refer to such regularities, yield a derivation of the Lorentz transformations. In other words, the empirical principles in a sense *explain* why special relativity is a Lorentz invariant theory.

7 Illustration via Bell's rockets

In this section, our goal is to illustrate many of the distinctions between qualified and unqualified approaches, and different kinds of explanation, with reference to a specific and famous thought experiment in special relativity due to Bell (2004)—namely, his thought experiment of the rockets.[22]

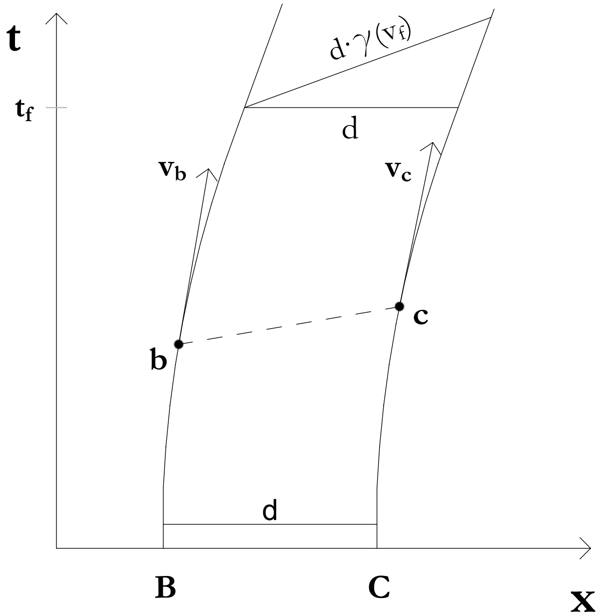
Recall that the details of this thought experiment are as follows (also illustrated in Fig. 2). Let S be an inertial frame in which two spaceships B and C are at rest, separated by a distance d. At time t_0 the spaceships, which are joined by a taut rope of length l, launch with identical acceleration programs (no deceleration). At a later time t_f, the spaceships stop accelerating and continue moving with final constant velocity v_f in S. Now, the physical behaviour of the rope after t_0 is a characteristic phenomenon in special relativity, and can be explained both in a kinematical and in a dynamical way. Let's begin with the kinematical account. We idealize the spaceships as point particles, so their trajectories are two non-inertial parallel worldlines B and C during the acceleration time. In frame S, the distance between the spaceships is at all times d, but after t_f the length of the rope contracts by the relativistic factor $\gamma^{-1}(v_f)$. Thus, the rope gets stretched, and depending on its internal constitution, the acceleration time, and the value of v_f, it can break. In S', i.e. the inertial frame in which the ships are at rest once they have stopped accelerating (notice that in S' ship C stops accelerating before ship B), the distance between them is $d \cdot \gamma(v_f)$ (where this time v_f is the relative velocity between S and S'), so the rope gets stretched in the same measure as in S (and it can break under same suitable conditions, of course).

What happens during the acceleration period can also be accounted for in kinematical terms. Let us pick an arbitrary event b on worldline B during the acceleration time. We take the tangent four-velocity vector v_b at that event and identify the inertial

[21] 'Constructive' here differs from 'constructive theories' in the sense of Einstein (1919). Einstein had in mind explanations *of phenomena* based on theories that feature a model of the microstructure and dynamics of matter. Here we have the erection of the kinematical structure of relativity theory from basic, empirically-informed axioms, which as explained by Adlam et al. (2025) is in fact more akin to a 'principle theory', in Einstein's terminology.

[22] For more on this thought experiment, see Flores (2005); Fernflores (2011); Read (2023b).

Fig. 2 Bell's thought experiment of the rockets



frame K_B that moves with velocity v_b in *S*, so the tangent vector v_b lies on the *t*-axis of K_B. We determine the simultaneity hyperplane in K_B on which *b* lies, and the event *c* in *C* that is simultaneous with *b* in that hyperplane. The tangent four-velocity vector v_c at *c* is not parallel to v_b. That is, for an observer in ship *B* at the instant in which *b* occurs ship *C* is moving away. We can construct the analogous frame K_C from an arbitrary event in *C* during the acceleration time, to find that for an observer in ship *C*, at the instant of that event, ship *B* is moving away. In both K_B and K_C, thus, the rope gets stretched. The events in *B* and *C* from which we build K_B and K_C, respectively, are arbitrarily chosen, and since we assume that there is no deceleration, as time goes according to the proper time of both *B* and *C*, the rope gets progressively stretched (the angle between the vectors v_b and v_c increases) until reaching the measure of stretch as determined in frames *S* and S' after the ships stop accelerating.

The kinematical account thus sketched shows that a taut rope joining two spaceships with identical acceleration programs will be stretched. However, it doesn't tell us whether or not it will break, nor when it will break if indeed it does. In the kinematical account, the rope is 'generic' in the sense that its material constitution is abstracted, so its internal dynamics during the acceleration time are left unspecified. The dynamical account of the thought experiment, on the other hand, focuses precisely on those abstracted elements. That is, an explanation of this type features a description of the microstructural constitution of the rope, and it requires a theory that governs its internal dynamics during the acceleration time.

The dynamical account of Bell (2004) uses Maxwellian electrodynamics to describe the electron-nucleus structure of the atoms that constitute the rope. Using this theory, he shows that (under suitable assumptions for the acceleration program) in frame *S*, for each atom in the rope the longitudinal radius of the electron gets contracted by a factor $\gamma^{-1}(v)$ and its period gets dilated by a factor $\gamma(v)$. To obtain these results, an expression for the field produced by the nucleus must be found, and also an equation for the motion of the electron in that field. Given the Lorentz contraction to which the atoms constituting the rope are subjected, the internal forces in the rope during the acceleration of the spaceships can be calculated (we need the relevant properties of the material of the rope, and the masses of the spaceships for this, of course), and then if and when the rope breaks can be predicted.

Bell's approach has a pedagogical goal, and he is aware that a dynamical account based on Maxwellian electrodynamics is not satisfactory—ultimately, of course, one will require recourse to quantum theory. However, an important point is that for guaranteeing coherence with the kinematical explanation presented above, the laws in the theory invoked in a dynamical explanation must be Poincaré invariant.

For the reasons explained in the previous section, we think that both unqualified approaches are unviable. The UGA states that in the kinematical explanation, it is Minkowski geometry that performs all the work (so the dynamical account is parasitic on the kinematic one). But as we've seen, there are just no firm grounds on which to defend that Minkowski structure enforces dynamics—either in a metaphysical or in a logical way—to be Poincarè invariant.

A similar objection can levelled against the UDA. This is clear when we compare it with the dynamical explanation of the Bell rocket setup that Lorentz's ether theory yields, which is also based on Poincarè invariant laws, but in a Galilean spacetime structure. Let us assume that S is an ether rest frame. This means that the rope stretches and eventually breaks because of internal forces due to the motion of the rope across the ether. However, in frame S' the dynamical account for the stretching of the rope results from a kinematical deception. The *real* distance between the ships is d, but due to deceived simultaneity determined by clocks in motion through the ether (which measure local time, not real time) and due to the Lorentz contraction of measuring rods, the measured distance between the ships when they stop accelerating in S' is $d \cdot \gamma(v_f)$. Thus, even if we explain the stretching of the rope in terms of its internal microstructure and dynamics in frame S', such description relies on a 'kinematical conspiracy'. In short, in the Lorentz theory the true dynamical explanation is formulated only in the privileged frame S. We can see then that although both special relativity and the Lorentz ether theory explain Bell's scenario in terms of Poincaré invariant dynamical laws, the resulting dynamical explanations are very different. A special relativistic dynamical explanation in terms of Poincaré invariant dynamics essentially requires a Minkowski kinematic structure. Therefore, the claim that in special relativity Minkowski spacetime structure is only a dispensable codification of Poincaré invariance seems unjustified. For the same reason, the claim that the kinematic explanation of Bell's scenario is dispensable and parasitic on the dynamical account is equally unwarranted.

As for the qualified approaches, precisely *because* these approaches are qualified the asserted epistemic hierarchy cannot be a matter of metaphysical necessity nor of mere conceptual analysis. Background views about the ontology of spacetime, commitments to empiricist epistemologies, or to specific types of explanation in science, are the sort of motivations, in the qualified views, for a defense that the stretching and eventual breaking of the rope in Bell's scenario is fundamentally a matter of dynamics or of geometry. As we suggested in the previous section, a prior preference for explanations of a constructive type (e.g., motivated by Salmon's conception of explanation) might lead to QDA and to the view that the correct and fundamental explanation of Bell's ships is the dynamical one, whereas a prior preference for structuralist or COI views on explanation might lead to QGA, and to asserting that Bell's thought experiment is satisfactorily explained in kinematic terms.

The counterparts view, on the other hand, assumes a qualified–pragmatic view about explanatory connections between dynamics and geometry in spacetime theories. Thus, in the case of Bell's scenario, this stance does not commit to a fundamental explanatory asymmetry. The dynamical or the kinematical account is the satisfactory and appropriate explanation of the behaviour of the rope depending on what is the why-question addressed. If we are interested in generic aspects of special relativity—e.g., if we are interested in what de Regt (2017) dubs 'understanding a theory'—kinematic aspects of the explanation in Bell's spaceships are crucial. On the other hand, if our question concerns when a specific rope in a Bell-type scenario breaks, the dynamical explanation is the correct approach.

8 Close

Let's wrap up. In this article, we've articulated one possible way of understanding the qualified/unqualified distinction which was introduced by Read (2020a) into the dynamical/geometical debate—namely, in terms of the kinematics/dynamics distinction; moreover, we've seen that on this way of understanding the distinction, the qualified/unqualified distinction turns out to be orthogonal to the dynamical/geometrical debate. While unqualified approaches in general are implausible (for reasons identified by Read (2020a)), qualified approaches are not so easily dismissed—but both QGA and QDA have interesting contrasts with the 'counterparts view' of Acuña (2016, 2025a, 2025b), which takes a more pragmatic attitude towards scientific explanation. We've explored in detail how these qualified views differ with respect to the explanatory accounts which they offer in the framework of special relativity, and have illustrated these with respect to Bell's thought experiment of the rockets.

Twenty years on from Brown (2005), it's remarkable that there remains fine-grained structure to resolve in the dynamical/geometrical debate. And yet, we hope that this paper—following in particular in the wake of prior studies by Read (2020a, 2020b); Acuña (2016, 2025a, 2025b)—makes evident that this is indeed the case, and that there remains much to be learnt from continued study of explanatory issues in the foundations of spacetime theories.

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