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Imagination in Scientific Practice

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Abstract
What is the role of the imagination in scientific practice? Here I focus on the nature and role of invitations to imagine in certain scientific texts as represented by the example of Einstein's Special Relativity paper from 1905. Drawing on related discussions in aesthetics, I argue, on the one hand, that this role cannot be simply subsumed under 'supposition' but that, on the other, concerns about the impact of genre and symbolism can be dealt with, and hence present no obstacle to regarding imagination as appropriately belief-like. By applying the framework of 'semi- propositional representations' and 'quasi-truth' to this case I thereby offer a new unitary framework for understanding the epistemology of scientific imagination.

Keywords Imagination · Supposition · Scientific practice · Symbolism · Semi-propositional representation · Quasi-truth

1 Introduction: Einstein's Invitation

Consider the following passage, taken from Einstein's classic paper, 'On the Electrodynamics of Moving Bodies' (Einstein 1905):

> "Let there be given a stationary rigid rod; and let its length be *l* as measured by a measuring-rod which is also stationary. We now imagine the axis of the rod lying along the axis of *x* of the stationary system of co-ordinates, and that a uniform motion of parallel translation with velocity *v* along the axis of *x* in the direction of increasing *x*

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> is then imparted to the rod. We now inquire as to the length of the moving rod, and imagine its length to be ascertained by the following two operations ..."

The passage continues,

> "We imagine further that at the two ends A and B of the rod, clocks are placed which synchronize with the clocks of the stationary system, that is to say that their indications correspond at any instant to the "time of the stationary system" at the places where they happen to be. These clocks are therefore "synchronous in the stationary system." ...
> We imagine further that with each clock there is a moving observer, and that these observers apply to both clocks the criterion established in § 1 for the synchronization of two clocks."

Here we appear to have an explicit invitation to engage the imagination and what I'd like to explore here is the nature of that engagement and its place within this example of scientific practice. Now, of course, the claim that imagination plays a role in scientific work is hardly a surprising conclusion but typically that role has been restricted in at least two senses, both to the heuristic phase of theory development, or what is sometimes called the 'discovery' stage (I'll come back to this below) and to specific aspects of scientific practice. Recently, however, those restrictions have begun to relax in various ways. So, for example, the role of the imagination in thought experiments and crucially, how that might change our view of the latter, has come under further examination (Arcangeli 2010; Meynell 2014 and 2018; Murphy forthcoming; Salis and Frigg forthcoming; Stuart 2017, forthcoming-a and forthcoming-b). And of course, the view of models as fictions has drawn on the role of the imagination in order to articulate those fictional aspects (see Frigg 2010; Salis and Frigg forthcoming; Toon 2012). However, in those cases we are invited to engage the imagination as part of a process of 'make-believe' (at least on the most well-known of such accounts), in which we imagine certain idealised elements of the model – such as the bob in a simple pendulum, swinging without air resistance – just as we imagine certain elements in a children's game of make-believe or in a work of fiction more generally (for a critical analysis of this sort of account see Weisberg 2013).

In this paper, however, I will look at imagination in what at first sight, at least, appears to be a different context – namely, that of the presentation of a theory, via a journal publication (although it could also obviously be in a seminar or conference presentation or similar). Furthermore, I shall argue against certain views that might be construed as attempts to diminish the role of imagination by disassociating it from belief in this context. In doing so, I shall adopt a framework that takes belief in p to be belief in the *quasi*-truth of p, where p is taken to be a 'semi-propositional representation' (da Costa and French 2003). This, I shall claim, opens up space for consideration of imagining as on a par with other elements of the relevant practice, such as proposing, entertaining and believing a theory or hypothesis and thus affords a greater appreciation of its role in that practice.

Before we consider such claims, however, there is a concern that needs to be dealt with 'upfront', as it were, lest it remain a nagging worry throughout the discussion.

2 Context

This concern has to do with the fact that Einstein's original paper was, of course, written in German and so there might be a worry that the phrase "Wir denken uns nun die Stabachse ..." although standardly translated as "We now imagine the axis of the rod …",[1] could be understood as an invitation to simply engage in 'thinking of' for example, rather than as an invitation to *imagine*, per se.[2] However, leaving aside the issue of why the accuracy of such a widespread and accepted translation should be doubted or why the translators would insist on using 'imagine' in this case when English alternatives are available, although 'denken' can indeed be translated as 'think', it is more appropriately read as 'imagine' when it is in the reflexive form, as it is here. [3]Having said that, there is also a sense in which this concern is a bit of a 'red herring'. Whatever Einstein's own intentions were in writing the original phrase, the English text itself has been widely reproduced and has had an enormous impact, so I shall take it as my example of an invitation to imagine in a scientific paper.[4]

Nevertheless, this offers a convenient point at which to reflect on the nature of imagining more generally. [5]There is, not surprisingly, a huge literature on this and little in the way of consensus when it comes to an appropriate taxonomy that covers all the different kinds of imaginings (for a useful overview see Liao and Gendler 2019). For my purposes, it will be useful to distinguish, at least initially, between sensory or imagistic imagination and propositional imagination (ibid; see also Arcangeli 2018 who draws the distinction between 'sensory' and 'cognitive' imagination). The former is concerned with the formation of mental images in some sensory modality – typically visual – and indeed, such imagery has historically been taken to be constitutive of imagining (Liao and Gendler *op. cit.*). [6]This historical force has been resisted, however, and propositional imagination, in which one represents to oneself that something is the case, does not involve such imagery. The mental state typically taken to be the counterpart to sensory imagination is perception and the counterpart to propositional imagination is belief. However, the manner in which imagination and belief differ is also a matter of debate (again, see Liao and Gendler op. cit.). Both can be understood as cognitive attitudes involving representation, but some have argued that the latter but not the former aims for the truth, whereas others have rejected this distinction. Some have tried to characterise the difference in terms of their connection to action, or lack thereof. Some have argued that belief and imagination lie on a continuum and still others maintain that the latter is ultimately reducible to the former. As we'll see, the framework I shall offer here blurs, at the very least, the purported distinction in terms of truth and, given the notion of belief in play, might be read, weakly, as compatible with the continuum view,

[1] This is how it is translated in (Einstein 1989) for example, by Anna Beck who translated the first five volumes of *The Collected Papers of Albert Einstein*, published by Princeton University Press.

[2] I'd like to thank Otávio Bueno, Juha Saatsi and an anonymous referee for pressing me on this issue.

[3] This has been confirmed by various people with the appropriate grasp of German, including a leading expert in the history and philosophy of space-time theory, to all of whom I am grateful!

[4] Nevertheless, the general concern about the legitimacy of translation and interpretation in this context should not be dismissed. As well as linguistic differences there have also been historical shifts in scientists' attitudes towards the imagination (see for example Illife 2018).

[5] I am grateful to an anonymous referee for pressing me on this.

[6] Todd argues that imagery can have important cognitive value because of its connection with certain affective states that themselves possess cognitive import. Thus, thought experiments, considered via the imagination, may evoke certain quasisensory intuitions on the basis of which new beliefs can be formed (Todd 2020).

or more strongly as reductive in nature. Finally, hybrid accounts have also been proposed, according to which '…imaginings have complex contents, only part of which are accounted for by the contribution of one or more mental images ' (Langland-Hassan 2015, p. 679). As we'll also see, there is a sense in which the imagining that Einstein invites us to engage in might be regarded as an example of this hybrid form.[7]

Let us now move on to consider the question, what is involved in accepting such an invitation to imagine?

3 Instruction and Intention

In formulating an answer to this question, we might draw on other such invitations, as implicitly made in works of fiction for example. Thus Stock in her account of fictional content, writes that "... a fiction is a set of instructions from authors to readers or hearers, instructing them to imagine various things as part of a single scenario." (Stock 2017, 174).[8]

One might be tempted to say, similarly, that 'A theory *is* a set of instructions from scientists to readers or hearers, instructing them to imagine various things ...' but that would lead us into a contentious debate over what theories *are* (see, for example, French and Vickers 2011; French 2020). Nevertheless, we can regard the *presentation* of a theory, or theoretical hypothesis, whether in a talk or in a published paper, as embodying certain instructions in Stock's sense and indeed, Einstein does seem to be giving us, the reader, explicit instructions to imagine here, as when he writes, "We imagine that at the two ends of the rod a clock is placed ..." The relevant scenario is obviously the arrangement of rods and clocks and here we are being told to imagine specific details of this arrangement.

However, one might balk at this importation of a certain understanding of fictions from the philosophy of art into the philosophy of science. It could be argued that Einstein's use of 'imagine' in these passages is merely a rhetorical flourish and that his invitation is actually to entertain a *supposition*, rather than to imagine per se. If this were the case, the passage from Einstein's paper would be much less noteworthy and our considerations here correspondingly less interesting! Let us then consider this further distinction that is sometimes made between imagining and supposing.

4 Imagination vs. Supposition

As with imagination, there is a huge literature on the nature of supposition and the distinction, if any, between the two. Although both may be viewed as similar sorts of

[7] Thus referring back to the translation of 'denken', it would be too quick to say that 'thinking' and 'imagining' can be distinguished by virtue of the fact that the latter goes hand in hand with visualisation, whereas the former does not. Of course if that *were* the case, it would provide further support for taking what Einstein wrote as an invitation to imagine since, as we'll see, it can be understood as involving a sensory element. Again I am grateful to an anonymous referee for raising this issue regarding the distinction between 'imagining' and 'thinking'.

[8] Stock defends a position known as 'extreme intentionalism' which holds that the content of a work of fiction is determined by what the author of that work intended the reader to imagine. I do not advocate such a position here.

mental activity (see Arcangeli (2017) for a useful survey of the various positions in play), imagination is typically taken to be capable of producing an affect, such as fear or desire and so on, whereas supposition does not. Supposition on the other hand is claimed to be relatively unconstrained, whereas imagination is constrained in various ways – we can suppose contradictions for example but, it is claimed, we cannot imagine them (see also Salis forthcoming).[9] Supposition is also understood to be 'coarse-grained' and lacking embellishment, as befits an attitude involved in counterfactual considerations, whereas imagination is taken to be more detailed and complex. Thus it might be suggested that what is going on in Einstein's paper is actually an invitation to 'suppose' rather than imagine *per se*.

Indeed, it has been argued that conflating supposing and imagining in the scientific context blurs certain important differences:

> 'Theorizing in empirical matters consists in employing something like the hypothetico-deductive model, whereas imagination does not. Imagination essentially involves forming quasi-sensory mental representations, whereas theorizing does not. Moreover, [the] view that supposition is a kind of imagination implies that the cognitive activity in dreaming or daydreaming is different only in degree, not in kind, from the cognitive activity involved in, say, constructing models in theoretical physics. This is implausible, though.' (Spaulding 2016, 220)

The contrast here is with a rather narrow view of 'theorizing' and many would accept that the relevant practices cover a wide range of activities and methodological devices, that cannot be straightforwardly captured in terms of a hypothetico- deductivist framework. If such practices are taken to include model construction more generally, it is not so implausible to suggest that what goes on in such construction is only different in degree from what goes on when a scientist day-dreams, the creative significance of which is well-known.[10] More significantly for what I shall say below, it is also not obvious that a clear line can be drawn between imagination and what is called 'theorizing' above when it comes to the involvement of 'quasi-sensory mental representations'.

Certainly, on the face of it, the passages from Einstein's paper above do reveal an aspect of his practice that seems to explicitly involve imagination. Granted the previous considerations about translation, to dismiss this as mere rhetoric might be viewed as a refusal to take the language used in scientific practice [11] seriously, something we would do well to avoid.

However, perhaps the crucial argument against drawing a firm distinction between imagination and supposition is that it leads to an unnecessary multiplication of mental kinds (cf. Gendler 2000). The view mentioned and dismissed as implausible in the passage cited above avoids such a cost by taking imagining to *embrace* supposing. Thus, Arcangeli (2018) argues that supposition should be regarded as a type of imagination, but one that is *sui generis,* standing distinct from both cognitive and

[9] The likes of Priest, of course, would disagree (Priest 2006).

[10] The exercise of the imagination in day-dreaming is taken to have a spontaneous element but one might argue that something similar takes place in model building, particularly with regard to its exploratory aspects.

[11] I am also taking this broadly, to include the language of texts such as the English translation of Einstein's paper.

sensory imagination in terms of its lack of constraint, emotional affect etc. as indicated above. Supposition, she maintains, is also a propositional attitude and the inferential relations holding between suppositions are similar to those that hold between beliefs. However, unlike belief, supposition, by virtue of being a speculative metal state, does not aim for the truth. Stock, on the other hand, argues that supposition can be regarded as a form of cognitive imagining but one that has a distinctive role in helping to determine the *identity* of the imaginative scenarios in which it features (Stock 2017). As for the claims that supposition is unconstrained as compared with imagination, or is coarse grained, affectless and so on, she argues that we should take these apparent characteristics as merely contingent and contextual features, given certain accompanying purposes, goals & uses (*ibid*., 202-207; for a critical response see Arcangeli 2017). Indeed, she suggests, these characteristics have been mistakenly regarded as distinctive primarily because of the general use of supposition in counterfactual reasoning. It is in precisely those situations, where the exercise of the imagination tends to be terse, focussed and lacking in detail, that there is a tendency to refer to it as 'supposition'. However, in other contexts, such as we find in fictional works, she maintains, supposition can be constrained, detailed and accompanied by appropriate emotions.

What about scientific works? Setting to one side the issue of emotional engagement with aspects of such works (but see Arcangeli and Dokic 2020), supposition is clearly *not* entirely unconstrained in this context, given the roles of background knowledge and assorted heuristic factors (for a classic consideration of the latter see Post 1971). It will also be more or less fine-grained, depending on the particular features of that scientific context. These brief considerations suggest that Stock's context dependent view of supposition meshes better with scientific practice. Returning to Einstein's paper, then, and following her account, we might take the core principles of relativity and constancy of the velocity of light – clearly constrained by a well-known variety of factors – as playing a suppositional role in her sense as they effectively delineate the relevant imaginative scenario – it is within that scenario that we are then invited to imagine the rods and clocks translated in a certain direction and so on. Indeed, in the context of this paper, we can see supposition and both cognitive and sensory imagination working together: having established the relevant scenario via the principles of relativity and constancy of velocity of light, understood as hypothetical in the appropriate sense, we are then invited to imagine their counterfactual consequences in terms of a certain scenario that does indeed involve certain 'quasi-sensory' elements insofar as it is articulated in terms of the familiar elements of clocks and rods (again, I'll come back to this).

5 Imagination vs. Belief

However, even if one were to concede that a hard and fast distinction between imagination and supposition is difficult to maintain, one might still insist that imagining occupies a distinctive role in the presentation and reading of a scientific theory insofar as it is not 'belief-like'. Here it is typically maintained that imagining is normally conscious, voluntary and under our intentional control, whereas belief does not possess these features. Beliefs also motivate us to take action, whereas imagination does not – it is 'quarantined' (Salis forthcoming). The content of our imagining is also typically taken to be inhomogeneous in nature and, it has been argued, the 'imaginative path'

taken does not necessarily proceed in a 'belief like' manner (Stock 2017, 177-178); that is, this path does not proceed via interaction with the usual inferential mechanisms that govern belief (cf. Currie and Ravenscroft 2002; Weinberg and Meskin 2006).[12]

When it comes to fictions, the basis for this last claim is two-fold. First, it is argued that the *genre* that such a work falls under will reinforce certain implied but unstated truths that the reader is encouraged to acknowledge during her reading.

Fictional genres, such as science-fiction, or horror, or crime, are governed (in some sense) by certain conventions (Stock 2017, pp. 68-74). And these conventions may, whether explicitly, through the publishers' blurb on the back of the book, say, or implicitly, through the reader's expectations, '… hermeneutically reinforce the reader's confidence about what fictional truths are implied but unstated in the text.' (ibid., p. 74). At first glance, at least, such 'hermeneutic reinforcement' does not obviously mesh with the more straightforward 'inferential pathways' that one associates with belief.

Furthermore, it is also argued, such imaginings may also incorporate certain *symbolic* elements that likewise cannot be accommodated via the usual belief related mechanisms. So, for example, suppose you are reading Jane Eyre and imagine that Jane is locked in a red room. You may believe that Brontë's use of a red room here was intended to symbolize a womb and thus you may then infer that Jane was affected by the loss of her mother. However, the content of your initial imagining and that of your belief are not true with regard to the same scenario. The first concerns an orphan girl and future wife of Rochester while the second has to do with the events – understood as fictional constructs – of a book written by Brontë. Thus, '[t]here is little obvious sense in which these two kinds of thought, one imaginative and one a belief, come into *direct* inferential content: for they take different scenarios as objects (the imaginary scenario of the novel, and the actual world, respectively).' (Stock 2017, p. 179).

Now, if imagination could be pulled away from belief in this manner, that would raise concerns as to whether it could be said to play an integral role in scientific practice of the sort that we find in Einstein's paper. It might even encourage the claim that such invitations to imagine should be dismissed as mere rhetoric.

However, as we'll now see, by extending a certain formal framework of belief in the scientific context to accommodate imagining we can better understand its role and by closer consideration of that context we can overcome the above obstacles to a belief-like imaginative path.

6 Clocks and Rods and 'Hooks'

Let us recall: imagining is supposedly not belief-like insofar as it is under our control and quarantined, its contents are inhomogeneous and the inferential path it takes does not proceed in an appropriately straightforward manner, due to the intervention of genre and symbolism.

In response, let us begin with a similar distinction that has been made between belief and acceptance, as articulated in terms of belief being essentially passive and involuntary in nature, whereas acceptance also involves a conscious and voluntary choice

[12] Again, these mechanisms may be more varied when it comes to what goes on in science than certain commentators appreciate.

(Cohen 1989; see also Elgin 2017 pp. 18-20). Beliefs, it is claimed, come over us 'willy-nilly', as it were, whereas acceptance involves an element of commitment. Likewise, when one imagines, or begins to imagine something, there is a commitment to the central features of that particular imagining, the consequences of which are then followed via the 'imaginative path' mentioned above. The parallel can be taken to provide further fuel for the claim that imagination is not 'belief-like'.

However, when it comes to scientific practice, there are obvious concerns about divorcing acceptance from belief in this manner, not the least of which is that it raises the spectre of rendering theory choice arbitrary or a matter of convention. One could appeal to the standard theoretical virtues in response (Schindler 2018) but of course their role in theory choice is contentious. Ultimately, it would seem, any attempt to assuage the concern must appeal, at some stage, to the 'observational element' of scientific knowledge (Cohen *op. cit.*, p. 386). But then, granted the much-discussed intricacies of experimentation and observation, ultimately, again, this does, of course, involve belief. Hence some connection, even if only indirect, between belief and acceptance can be restored, via this grounding in observation, albeit mediated. I'll return to that connection shortly but first let me note that we can draw a further comparison here with the kinds of invitations to imagine that we find in examples such as Einstein's paper.

Here too we can find something akin to these 'observational elements', namely the 'quasi-sensory' aspects of the imagining noted above. In the case of Einstein's paper specifically, we have the clocks and rods with whose behaviour we are expected to be familiar. The emphasis on these, as in the passages quoted at the beginning of this paper, has in the past been used to support the view that Einstein, at this stage of his career, displayed positivistic tendencies, a view that has since been dismissed (see for example Howard 2017). Nevertheless, the significance, both epistemological and physical, of the clocks and rods should not be downplayed.

Understood as primitive they imbue the space-time interval with a physical significance that was carried over into the General Theory, in effect providing gravity-independent grounds for that theory. Crucially, and fundamentally, Einstein stipulated the clocks to be 'perfect' and the rods as 'practically rigid', qualities that the Special Theory itself ruled out for the corresponding physical entities (Shapere 1969). Thus as idealised entities these clocks and rods could only be imagined and it is for this reason that Einstein phrases these passages in this manner.[13]

It is by virtue of this significance that these elements function as the 'hooks' on which one can hang the 'belief-like' features of this particular case of an invitation to imagine. Of course such hooks may not be and typically will not be present in all cases of imagining but here I am concerned only with its role in scientific contexts.[14]

Furthermore, by placing such elements within the imagination, as it were, the reader is encouraged to consider them as stripped of unnecessary or irrelevant detail, so that their function can be more readily grasped.[15] And as just indicated, that function is to act as primitive and idealised elements that have a quasi-sensory nature.

[13] Sorensen (2013) argues that all idealisations are suppositions and holds that the latter are not belief-like, since false suppositions – such as idealisations – can still be useful, whereas false beliefs are a different kettle of epistemic fish. The framework of 'quasi-truth' to be presented below embraces both.

[14] This is a feature shared with at least some examples of thought experiments; see Murphy forthcoming.

[15] Again, a useful comparison might be made with certain thought experiments, such as Newton's bucket for example.

7 Restoring the Connection Between Acceptance and Belief

What, then, is the connection between acceptance and belief when it comes to scientific theory choice? And how might we appropriate it to render imagination 'belief-like'? Here I shall draw on elements of the framework of 'quasi-' or partial- truth as set out in (da Costa and French 2003).

Thus, underpinning the relevant discussions of belief and acceptance is a common assumption that belief should be cashed out as belief that *p*, where *p* is some *proposition*, taken to be true. Likewise, this assumption threads through debates over the nature of (propositional or more broadly, cognitive) imagination and whether it may be regarded as belief-like. However in both cases, it can be argued that '*p*' should be taken to be more complex, less 'homogeneous', as open-ended and so on and less directly tied to the evidence such that 'belief that *p*' is not involuntary and thus distinct from 'accept that *p*' in the manner of the above claim (da Costa and French 2003, Ch. 2). What is needed, then, is a characterisation of the subject of our beliefs, that is, the '*p*' in 'belief that *p*', that can accommodate the above features that have been taken to support the claims that neither acceptance nor imagination is belief-like, as we have seen.

Here we might usefully draw on another example, this time from anthropology: during his years of field-work in Ethiopia, Sperber encountered an old man who urged him to kill a dragon that he imagined (crucially) to live not far away. Couched in terms of propositions that must be regarded as true or false, the man's belief in the existence of a dragon might appear irrational. However, Sperber resists such a dismissal and instead argues that an appropriate epistemic attitude should be adopted but that the object of such an attitude should not be regarded as strictly propositional in character. Instead, he suggests, we should replace *p* above with what he calls a 'semi-propositional representation' (Sperber 1982).

Now, these are 'conceptual representations' that do not have fully fixed propositional content and may be 'entertained', as conceptual possibilities, say. They are generally not 'homogeneous', may even accommodate inconsistencies, and in suggesting a range of interpretations are heuristically fruitful and open-ended. Thus, Sperber writes that,

> ' ... a semi-propositional representation can be given as many *propositional interpretations* as there are ways of specifying the conceptual content of its elements. In principle, one of these interpretations is the proper one: it identifies the proposition to which the semi-propositional representation is intended to correspond.' (Sperber 1982, 169)

On this basis a further distinction can then be drawn between 'factual' beliefs, where there is awareness only of (what to the subject is) a fact and 'representational' beliefs, where there is awareness of a *commitment to a representation*. The rationality of holding the former can be cashed out in terms of evidential support directly involving observation, whereas that of holding representational beliefs of semi-propositional content is to be explicated in terms of a warrant that is mediated in certain ways, including via the beliefs of other epistemic agents (da Costa and French 2003, Ch. 4). Thus, we may hold a factual belief in the proposition 'the snow is white', where this is understood as believing that 'the snow is white' is true, in the correspondence sense,

given the evidence of our senses. And both we and a high energy physicist, say, may believe, 'representationally', that 'quarks are coloured', given the respective mediations of the warrant for that belief: for us it may involve our epistemic dependence on, and trust in, the physicist who asserts such a sentence, whereas for the latter it will embrace a variety of well-known inter-theoretical and, crucially, theory-evidence relationships (*ibid.*). In both cases, the chain of epistemic dependence terminates in a factual belief of some kind, associated with the relevant evidence. This distinction between factual and representational beliefs can then be deployed in the context of theory choice, with Sperber's notion of a 'semi-propositional representation' formalised in terms of partial structures, taken to represent scientific theories within the framework of the Semantic Approach (da Costa and French 2003). This can in turn be extended to accommodate imaginative episodes in scientific practice, as represented by the example of Einstein's paper above.

8 Imagination and Quasi-truth

Thus, it has been argued, scientific (theoretical) beliefs in general can be understood as *representational* beliefs, in precisely the above sense; that is, in p as *quasi-true*, where this latter notion can be formalised à la Tarski via so-called 'partial structures' (*ibid.*). The formal details are as follows (see da Costa and French 1990 and, again, 2003):

A partial structure is a set-theoretic construct $A = \langle D, R_i \rangle_{i \in I}$, where D is a non- empty set and each R_i is a partial relation. A partial relation R_i xover D is a relation which is not necessarily defined for all n-tuples of elements of D (see da Costa and French 1990, p. 255). Each partial relation R can be viewed as an ordered triple $\langle R_1, R_2, R_3 \rangle$, where R_1, R_2, and R_3 are mutually disjoint sets, with $R_1 \cup R_2 \cup R_3 = A^n$, and such that: R_1 is the set of n-tuples that (we take to) belong to R; R_2 is the set of n- tuples that (we take) do not belong to R, and R_3 is the set of n-tuples for which it is not defined whether they belong or not to R.[16]

We can then define a notion of quasi-truth (see, again, da Costa and French 2003) as follows: If B is a total structure, whose relations of arity n are defined for all n-tuples of elements of its universe and the language L of the partial structure A is also interpreted in B, and P is a set of accepted sentences, then B is said to be A- normal if:

(i) the universe of B is A;

(ii) the relations of B extend the corresponding partial relations of A;

(iii) if c is an individual constant of L then in both A and B c is interpreted by the same element;

(iv) if $s \in P$, then $B \models s$.

[16] If we have two such partial structures, partial isomorphisms can be defined between them, allowing us to capture, it is claimed, both the inter-theoretical and theory-evidence relations mentioned above (Bueno 1997; French and Ladyman 1999).

In other words, loosely speaking, a total structure B is called A-normal if it has the same similarity type as A, its relations extend the corresponding partial relations of A, and the sentences of P are true, in the Tarskian sense, in B. Then a sentence s is said to be *quasi-true* in A, or in the domain D that A partially reflects, if there is an interpretation I of L (and consequently of s) in an A-normal structure B and s is true in the Tarskian sense in B. Clearly, A is not conceived of as reflecting the (total) structure of D, but as only partially mirroring this domain. Thus the partial structure A has to capture some fundamental aspects of D, or some 'elements of truth', although it does not mirror D perfectly. Then, we can say that s is quasi-true in A, if all logical consequences of s are compatible with any true primary statement in P. In other words, s is quasi-true in the partial structure A if there exists an A-normal B in which s is true, in the correspondence sense. If s is not quasi-true in A according to B, then s is said to be quasi-false in A according to B.

Hence, in a report of a representational belief of the form 'belief that p', the suggestion is that the sentence p should be regarded as partially or quasi- true in the above sense, while the semi-propositional content of such beliefs is formally expressed by the relevant partial structure which in representing our (partial) knowledge of the domain concerned is the *object* of the belief. My claim is that by means of this framework we can also accommodate the way in which the subject of the imaginative endeavour is not homogeneous, is open-ended and can be regarded as quasi-true.

First of all, the distinction between 'factual' and representational' belief nicely meshes with invitations to imagine of the specific kind we are considering here and with p understood in terms of such semi-propositional representations in the imaginative context we can restore the connection between imagination and belief. Furthermore, the relevant 'semi-propositional representation', as formalized via a partial structure, will contain various elements and as indicated above, is open-ended in that it supports a range of propositional interpretations.

9 Back on the Imaginative Path

What about the claim that beliefs motivate action whereas imaginings do not, and are effectively 'quarantined'? It goes without saying that the imagination may motivate action in a broad sense but the claim has to do with the phenomenon whereby the attitudes involved in an imagined state of affairs are typically not taken to be relevant to guiding action in actuality (again see Liao and Gendler 2019 for further discussion). Nevertheless, 'contagion' may sometimes occur, as when the content of an imagining ends up shaping our perceptions or beliefs in general (*ibid.*). And again the above framework would seem able to accommodate this: consider Sperber's 'dragon' case, for example. Here we can speculate that the old man's request that Sperber kill the purported dragon, understood in terms of a semi-propositional representation, was motivated by some imagining or other, itself conditioned by background knowledge, including certain traditional and cultural beliefs. We can further extend this form of imaginative contagion to scientific cases, such as Blondlot's infamous but erroneous claim to have discovered 'N-rays' (see https://www.aps.org/publications/apsnews/200708/history.cfm). Here we might suggest that Blondlot's imagining of ray-like phenomena, conditioned by the recent discovery of x-rays, led him to 'perceive' such phenomena in his laboratory (see also Nye 1980). Again,

the nature of the relevant belief in this case can be appropriately characterised as 'representational' in the above sense. Whether 'contagious' imaginings can play a more positive role in science is a matter for another occasion but the point I wish to emphasise here is that imaginings may not always be quarantined – and so this distinction from belief may also be eroded – and that when they are not, the framework of semi-propositional representations can also accommodate them.

That still leaves the claim that the relevant 'imaginative path' is not 'belief- like'. We recall that this is because, in fictional imaginings, at least, genre and symbolism conspire to push us off such a belief-like path. Here we need to consider carefully the extent, if any, to which these features can be carried over into science and whether, if they can, the scientific imaginative path is such that either feature could compel us to regard that path as not 'belief-like'. As we'll see, in the case of genre, we can answer that it does not so compel us whereas when it comes to symbolism, it can be argued that this cannot be carried over at all, at least not in the same form.

So, consider the way in which the 'genre' of a fictional work is supposed to take the reader off the well-beaten inferential path associated with belief, as noted above. It does this by means of the implicit assumptions associated with the genre: we don't need further justification why the chap with the elongated incisors bursts into flame in a horror novel, for example. A particular genre introduces its own kinds of objects and tropes – vampires and zombies, for example, or aliens and spaceships – together with its own set of criteria for evaluating the veracity of claims about such objects. A given genre is thus 'self-authenticating' in the sense that it provides its own criteria for what is justifiable, although those criteria may be more or less flexible (compare, for example, the zombies of *The Walking Dead*, comic and tv show, with those of the movie *28 Days Later*). Granted that, genres are typically stable over time, having developed their own means of adjusting to changes and pressures, both internal and external.

With these characteristics in mind, we might usefully compare this notion of 'genre' with Crombie's idea of 'styles of reasoning' in science, in the sense of distinctive ways of scientific knowing that emerge at certain points in the history of science (Crombie 1994). He identified six, taken to be neither exclusive nor exhaustive: postulational, experimental, hypothetical, taxonomic, probabilistic and statistical, and historical or genetic. As with genre in fiction, such styles 'hermeneutically reinforce' our confidence about what truths are implied but unstated in the relevant scientific practice. Hacking then famously claimed that these styles introduced new kinds of objects and new criteria for the truth or falsity of statements about those objects (for a comparative analysis see Sciortino 2017). Furthermore, he argued, a given style is self-authenticating in the sense that it defines its own criteria of validity and objectivity, and it also develops its own techniques of stabilisation.

Finally, he insists that each style is grounded in our cognitive capacities that are the product of both evolution and cultural development.

Apart from that last feature, there seems to be a straightforward comparison with the outline of genres sketched above. The first of Hacking's claims is obviously contentious in the scientific context (for further consideration see Ruphy 2016)[17] but perhaps less so in that of literary genres, as already suggested. And both fictional genres fiction

[17] A realist would of course insist that although such a 'style of reasoning' may offer new ways of describing or conceptualising certain objects, it does not bring such objects into existence.

and scientific 'styles' can be seen as self-authenticating and self-stabilising. What this illuminates is that the more straightforward 'imaginative path' against which the unfolding of imagination in fiction is compared may not be present in science either and hence simply pointing to the existence of genre or styles of reasoning is not sufficient to demonstrate that the relevant imagining is not 'belief- like'. Indeed, if such genres or styles are regarded, rather broadly perhaps, as constraints,[18] then their impact on the imaginative path might be less disruptive than initially thought – certainly in the scientific case, at least.

In that case, that scientific beliefs are constrained or even shaped by appropriate conventions or may be considered to be embodied in particular research programmes or overarching theoretical frameworks and so on is, of course, hardly contentious. In the relativistic case, for example, we might appeal to Lorentz invariance as the appropriate constraint, in the context of the associated significance given to symmetry principles in general. In the specific example of Einstein's paper we might take the equivalent of 'genre' to be embodied in his adoption of what Crombie calls the 'postulational' style as reflected in the way he presents the constancy of the speed of light, for example, as already considered above, as well as in the commitment to Maxwellian electrodynamics, with the various implicit truths thereby implied. Indeed, we have already noted that the scientific imagination in general is constrained in various ways like this, together with the role of background theoretical and experimental knowledge (Salis forthcoming; Stuart forthcoming-b).[19]

When it comes to symbolism, on the other hand, and its role in disrupting the 'imaginative path', one might worry that this cannot be accommodated quite so straightforwardly. Recall the example from *Jane Eyre*, when Jane is locked in a red room, where this meant to symbolise the womb, from which, in conjunction with other elements, we are supposed to infer that she is affected by the loss of her mother. The claim is that two kinds of thought are involved here – the imagining of Jane in the red room and the belief that this is intended to symbolise the womb – but they do not come into direct inferential contact, involving as they do different scenarios (Stock 2017, pp. 178-179).

However, it is not at all clear that we are ever expected to make such moves when it comes to scientific practices. Consider another example from the world of art, namely that of 'vanitas' paintings from the Netherlands in the 16th and 17th centuries. There we find certain elements within the painting – typically a still-life of some sort – that are supposed to symbolize the futility of life and the inevitably of our death, where these elements may be explicit, such as skulls or skeletons, or less so, as in a lemon, half peeled, apparently standing for time passing and the bitterness of life. Now, recent years have seen numerous attempts to construct accounts of representation that are capable of embracing representation in both art and science and within certain of those accounts such symbolic elements have been accommodated, in one form or another. Thus, for example, Frigg and Nguyen's influential 'DEKI' account incorporates the notion of a 'key' that, in effect, unpacks the relevant

[18] Dubrow (1982) rejects the idea that genres have a deterministic impact, or that readers' reaction to them can be codified in an 'if/then' pattern; rather, she suggests a genre might be usefully compared to a human personality, not least in displaying certain traits in different ways and in incorporating traits from different personality types while still conforming to one such type (*ibid*., p. 117).

[19] It has also been argued that some kinds of imaginative exercises do follow a certain kind of logic (Berto 2018). Having said that, such a 'logic' and the relevant constraints more generally should be understood as context specific and not straightforwardly generalisable as norms (Stuart forthcomingb).

symbol for us (Frigg and Nguyen 2017). In the case they examine – that of a painting of an 18th century noblewoman – it is the small dog in the picture that is 'keyed up' to represent fidelity; in the example of the 'vanitas' paintings above it would obviously be the half-peeled lemon to which the relevant key would apply.[20] Obviously, the 'shape' of the key, as it were, and the ability to unpack the symbolism will depend on a complex nexus of relevant background knowledge, including certain cultural conventions and presuppositions (and in such cases consideration of the relevant genre – still-life paintings for example – might be relevant). So, in the case of a lemon, viewers of such a painting in the 17th century would immediately appreciate that such a relatively exotic fruit, not native to the Netherlands, was indicative of some degree of wealth (Sonneman 2012) and anyone who has tasted one, whether in the 17th century or today, would appreciate the connection to bitterness!

Do we encounter anything along these lines when it comes to scientific theories or models? It would seem not. This is not to suggest, of course, that science does not deal with symbols. As with the words on the page in a work of fiction, certain marks in a paper or book or on a whiteboard are taken to denote certain physical properties. But typically what the symbol stands for here is given explicitly; so, in the case of Einstein's paper with which we began, we are told upfront that v stands for velocity. More generally, it would seem that by virtue of not incorporating elements that are 'keyed up' in the above manner, scientific representations differ from artistic ones. In other words, when it comes to texts like the 1905 paper, we don't have features like that of *Jane Eyre*'s 'red room' that require us to make this move of inferring a 'hidden' interpretation of some kind, based on some implicit understanding or social convention. In this sense reading a scientific paper is different from reading certain works of fiction. But then of course, the fact that such symbolic features are absent in the scientific case simply means that this does not constitute an obstacle to taking imagination to follow a 'belief-like path' in this specific case (unlike in a fiction, say).[21] This removes the second obstacle to regarding imagination as 'belief-like'.

Thus, with the idea that the 'object' of the imagining is a 'semi- propositional representation' as sketched above, together with an understanding of the associated attitude of belief as belief that such a representation is quasi-true, and an appreciation of the relevant style of reasoning in play and any constraints, we have an appropriate framework within which we can consider Einstein's invitation to imagine as appropriately 'belief-like', in line with what is presented in the rest of his paper. In other words, the relevant passages appealing to the imagination can hence be considered as an integral and important part of scientific practice as a whole, with regard to the epistemic attitude that should be adopted.

10 Imagination and Knowledge

One might be tempted to go even further and argue, as Williamson does, that imagination also provides *knowledge* (Williamson 2016). In particular, it has been widely

[20] As well as transience and the underlying bitterness of mortal life, lemons were also taken to represent fidelity, apparently.

[21] If an example from science were to be given that does exemplify this sort of move, I would argue that it further demonstrates that imagination does play a significant role in theorising, just not the sort of 'belief-like' role that I am concerned with here.

acknowledged that the exercise of imagination allows us to prepare for certain practically relevant possibilities. So, for example, prior to jumping across a stream, say, we may imagine ourselves doing so, thereby preparing ourselves for the leap. Williamson claims that such a capacity has obvious evolutionary advantages, and in order to confer them, he suggests, it must be both selective and 'reality oriented' and must operate both voluntarily and involuntarily, in which respect it resembles attention (*ibid.*). We can choose to imagine succeeding in jumping across the stream, or failing, and in this respect the exercise of the imagination is voluntary but having chosen a particular initial condition, as it were, the unfolding of the consequences, along a particular imaginative path, is involuntary of course (*ibid.*)

There is an immediate objection, however: insofar as this characterisation involves only the raising of possibilities, imagination provides, at best, only 'how- possibly' knowledge (cf. Reutlinger et al. 2018). Thus, when it comes to science, at least, this would encourage us to consign imagination to the context of discovery, or perhaps of pursuit (see, for example, Nyrup forthcoming; also da Costa and French 2003 pp. 115-129), rather than that of justification (Williamson 2016), as noted at the beginning of this paper. Bracketed off in that way, it may well be belief-like in nature but it could not be said to provide 'how-actually' knowledge. Nevertheless, Williamson argues, in the scientific case, at least, such a bracketing collapses under the reliance of science on mathematics, whose first principles are indeed justified via 'unashamed appeals to the imagination' (*ibid.*).[22] Thus he concludes, the role of imagination in justification seeps through the body of science via the dependence on mathematics and hence it can be regarded as providing 'how-actually' knowledge about the world.

This is clearly problematic, dependent as it is on a particular view of the foundations of mathematics and its applicability to science. In response, one can argue that, even granted the claim that mathematics does involve an 'unashamed' appeal to the imagination, the relevant dependence of science on mathematics is such as to prevent any such seepage. So, for example, if one were to maintain that mathematics plays only a representational role in science (Saatsi 2011) such that it affords us a grasp on certain physical dependencies (Strevens 2008) then any knowledge-via-imagination accruing to the former cannot be taken to be passed on to the latter. Thus, the relevant knowledge will be about the mathematics only, and not about the world.

At this point someone might gesture at two ways in which the mathematical intrudes into the physical, allowing for one form of knowledge to blur into the other. The first concerns what Wigner called the 'unreasonable effectiveness' of mathematics in physics (Wigner 1960), which might suggest some form of dependence between the two that prevents us from drawing such a hard and fast distinction when it comes to providing knowledge. However, the apparently unreasonable nature of this effectiveness evaporates when we consider actual examples in all the relevant detail and note the moves made to bring both the relevant mathematics and physical theory into contact (Bueno and French 2018). The second concerns the purported role of mathematics in explanation (see, for example, Baker 2009). Again, if it could be convincingly argued

[22] The discovery-justification distinction is famously problematic of course and itself may be taken to collapse, for entirely separate reasons. Indeed, it has been argued that the same epistemic attitude can be maintained across both domains, namely that of belief in the theory as quasi-true in the above sense (da Costa and French 2003, Ch. 6).

that mathematics plays an ineliminable role in explanations of physical phenomena, then insofar as we have justifications of the relevant beliefs and the explanations are factive, it could be concluded that the mathematics provides knowledge of the world. However, such arguments can be undermined through, again, a closer examination of the role played by the mathematics in specific cases (Saatsi 2011; Bueno and French 2018, Ch. 9) which reveals, again, that this is only representational; and so, again, this conclusion can be resisted.

More generally, it has been argued that we need to supplement our imaginings on any matter with certain background information and in particular when it comes to scientific cases, recalling the previously noted point about constraints, relevant theoretical knowledge pertaining to the subject matter at hand (Spaulding 2016; Stuart forthcoming-a and forthcoming-b). Imagination on its own cannot go beyond the 'how-possible' to provide knowledge of the world (but then, neither of course can belief!).

In this context, the above distinction between how-possibly and how-actually knowledge is reflected in Salis' contrast between knowledge claims about the imaginary system under consideration and knowledge claims about reality generated *via* the imagination (Salis forthcoming). In the case of Einstein's paper, the former pertain to the possible behaviour of the (idealised) clocks and rods as set out in that paper and the latter to the actual behaviour of actual clocks and rods as incorporated within concrete physical systems. It is the latter, of course, that comes to be represented as evidence about which we hold factual beliefs. Knowledge claims about imaginary set-ups play an important role in helping to establish knowledge claims about reality, just as mathematics does, but of course, the point remains, that such establishment is ultimately only achieved via engagement with reality, by means of observation (of some form or other), say.

Thus, we can maintain that imagination in science is belief-like, in the above sense, and in that sense is on a par with the other relevant elements of scientific practice in general, without committing ourselves to the view that in and of itself, it provides knowledge.

11 Final Remarks

Certainly there is more to say about the role of imagination in such practice and its engagement with these other elements and forms of reasoning that are involved. My intention here is primarily just to emphasise that it does play some such role and that it can be situated within a unitary epistemic framework, namely one shaped by representational belief and the notion of quasi-truth. On the one hand, as already indicated, this allows us to accommodate imagination within a framework that also captures other features of scientific practice, such as models and idealisations, for example (da Costa and French 2003). Furthermore, given the critical role that imagination is typically taken to play in scientific creativity, such an accommodation may then be viewed as placing the latter notion more centrally within the philosophy of science.

On the other hand, we might speculate that the above framework of representational belief might be extended further into the epistemology of imagination itself. We recall that Sperber's notion of a 'semi-propositional representation' was originally proposed to bring 'into the fold', as it were, apparently irrational beliefs, as in the case of the old

man and the dragon. Consider also 'pretense behaviour' and the issue of how that relates to belief (for a quick summary, see Liao and Gendler 2019): viewed from a 'Sperberian' perspective, we may see such behaviour in a new light that allows us to sidestep the traditional division between regarding belief and imagination as existing on a continuum and taking the latter as reducible to the former. Likewise, consider the comparison between imagination and so-called 'episodic' memory (memory involving mental content about one's own past): how significant should we take the apparent differences between the two (ibid.)?

Michaelian, for example, has recently argued that such memories are an evolutionarily adaptive form of imagining, involving representations with content that goes beyond that of past representations (Michaelian 2016). With remembering understood as a kind of imaginative simulating on Michaelian's account, the framework of semi-propositional representations and quasi-truth may help alleviate certain concerns regarding such a constructivist approach. However, this is all to step well beyond the issues touched on in this paper.

Finally, and returning to the latter issues, the role of the above kinds of invitations and of imagination in general in papers like Einstein's, and other examples of scientific work, reveals that the set of practices involved in such work and our engagement with those practices (through reading papers, listening to talks etc.) is more complex and heterogeneous than it is often portrayed. Having said that, it is also noteworthy that we can begin to make sense of that complexity and heterogeneity by productively importing certain moves and devices from the philosophy of art into our considerations of such practices within the philosophy of science, whilst also acknowledging the differences between the two domains and the limitations of such devices. Although it is not the case that all the features attributed to the imagination when it comes to fictions, for example, can be straightforwardly carried over to scientific theories, the extent to which we can draw on the former to illuminate the nature of the latter is significant and suggests that the philosopher of science might profitably view the philosophy of art as offering a useful set of tools to be appropriated and deployed in the service of a better understanding of science (subject to relevant caveats, of course; see French 2020).

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