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Opinion Piece: From conceptual change to scientific imagination: An interdisciplinary workshop at the crossroads of HPS and science education research

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Introduction

On June 4th 2021, the Freudenthal Institute and Descartes Center (Utrecht University) hosted an online interdisciplinary workshop on conceptual change. The main aim of the workshop was to reflect on various aspects of conceptual change by bringing together scholars from the fields of history and philosophy of science (HPS) and science education. The workshop included eight talks by an equal number of HPS scholars and science education researchers, including keynote lectures by Stella Vosniadou and Paul Honingen-Huene. In this article, the workshop organisers (Alstein and Verburgt) and two of its speakers (Kersting and Rijken) present their reflections on the workshop and the resulting cooperation.

Although it is widely recognised that HPS and science education researchers have much to offer each other, their potential collaboration is often hampered by differences in disciplinary traditions and terminology. As a result, while HPS scholars and science education researchers may be working on the same problems, insights yielded in one discipline often remain unexplored in the other. One way to bridge this divide is to identify shared topics of interest that lay the ground for joint exploration and fruitful collaboration. The present authors are convinced that such collaboration makes necessary a shared vocabulary in which insights from both disciplines can be expressed and communicated to each other.

Conceptual change is a paradigmatic example of such a shared topic across HPS and science education (Vosniadou, 2008). In HPS, conceptual change refers to the adjustment, re-evaluation and increased understanding of 'the scientist's conceptual apparatus' (Kuhn, 1966, p.242). Much emphasis in contemporary HPS is laid on the "practices of scientists in creating conceptual change, not on the conceptual structures per se" (Nersessian, 1998, p.160). In science education, most research in conceptual change describes students' difficulties and progressions in establishing scientific concepts by adapting an individual perspective, although conceptual change can be approached from social perspectives too (von Aufschnaiter & Rogge, 2015). During the workshop's (keynote) talks and plenary discussions, the workshop participants used the central topic of conceptual change to learn from each other and explore the relationship between HPS and science education research.

In particular, the workshop focussed on the following questions:

- How have HPS and science education research informed and influenced each other's views on conceptual change over the past decades until the present?
- What is the relation between recent debates in HPS and science education research on theories and models of conceptual change?
- What is required to make respective insights into conceptual change of mutual benefit?

In this article, we build on and extend our joint reflections to describe how discussing the notion of conceptual change has led us toward the topic of *scientific imagination*. As we will indicate below, both scientists and students seem to draw extensively on imagination and imaginative practices during processes of conceptual change. We argue, therefore, that the scientific imagination can be used as a key concept to answer the questions posed during the workshop. We will particularly indicate how recent insights from HPS and science education research into the notion of scientific imagination may be fruitfully combined to increase our understanding of conceptual change in science and science education.

Question 1: Looking back

Let us start by addressing the first question: how have HPS and science education researchers informed and influenced each other's views on conceptual change over the past decades until the present? It appears that the interaction between HPS and science education research has hitherto at best been asymmetric. Asymmetric because the influence appears to be mainly in the direction from HPS to science education, not the other way around. In her talk at our workshop, for example, Stella Vosniadou made the following remark:

> HPS-based conceptual change research has led science education researchers and educators to ex-

> amine more closely the nature of students' knowledge base – their preconceptions, misconceptions, and alternative conceptions – illuminating the failures of traditional approaches of teaching science to bring about science understanding. It has produced a much richer picture of the many conceptual changes – in ontology, epistemology, in representations of the world – as well as in basic cognitive and metacognitive capabilities students need to develop in the process of learning science. It has created a revolutionary shift in teaching science, from focusing on the transmission of facts to an appreciation of science as a discipline, of the scientific method, and of science's contributions to society. (Vosniadou, abstract for workshop)

One essential skill that students need to develop in science learning was mentioned repeatedly during the workshop: adequately employing imagination to bring about conceptual change. Floor Kamphorst, for example, described in her talk how secondary-school students reason scientifically through hypothetical modelling. In special relativity education, students perform the imaginative act of thought experiments to explicate their pre-instructional models of light propagation. In tasks, students relate these pre-instructional models to historical notions of light propagation: Newton's idea of light as tiny particles and Huygens wave description of light. Students can then build on these notions to understand the light postulate (Kamphorst et al., 2021).

Relatedly, Sam Rijken argued in his talk how a Waltonian view of the scientific imagination (discussed below) enables us to construct and present thought experiments in science education with increased precision and clarity. Magdalena Kersting, for her part, drew on Bertrand Russell's (1925, p.9) observation that learning general relativity demands a change in our imaginative picture of the world: "A change in our imagination is always difficult, especially when we are no longer young. The same sort of change was demanded by Copernicus, who taught that the earth is not stationary, and the heavens do not revolve about it once a day."

Question 2: Towards scientific imagination

Concerning the second question - what is the relation between recent debates in HPS and science education research on theories and models of conceptual change? - we believe that the concept of *scientific imagination* illuminates a relevant relation between recent debates in HPS and science education research.

The HPS contributions at the workshop reflect a recent trend in the field: the epistemic role of the imagination in science is currently being actively studied in the context of scientific modelling and thought experimenting. The recent collection *The Scientific Imagination* (2020) is exemplary in this regard[1]. Consider the following passage from its introduction, which echoes Vosniadou's statement above:

> Despite its centrality, the imagination has rarely received systematic attention in philosophy of science. This neglect can be attributed in part to the influence of a well-known distinction between the context of discovery and the context of justification (Reichenbach 1938), and a tendency in positivist and post-positivist philosophy of science to set aside psychological aspects of the scientific process. That

[1] In a recent review, Meynell writes justly: "'The Scientific Imagination' is, in some ways, an odd name for the book as the real focus is on scientific models (SMs) and thought experiments (TEs). TEs and SMs are types of representational objects, so focusing on them tends to elide other subjects that naturally belong in a discussion of scientific imagination—such as creativity, aesthetic value, or the role of emotions in science. " (Meynell, 2021, p.1)

> situation has now changed, and a growing literature in the philosophy of science is devoted to the role and character of imagining within science. This has been especially visible in the literature on scientific modeling, but the interest now extends more broadly. (Scientific Imagination, p.5)

This article discusses two branches in the HPS literature on imagination, both of which connect to science education research. The branches correspond to a distinction that is commonly made between two different *types* of imagination: *objectual* imagination and *propositional* imagination (e.g., Levy & Godfrey-Smith, 2020, p.5-6; Liao & Gendler, 2020, §1.2; Salis & Frigg, 2020, p.26). Objectual imagination is often discussed in connection to the scientists' context of discovery which, as we will indicate below, has a clear parallel to the students' context of learning science. Propositional imagination is currently mainly discussed through the concept of *make-believe*–an explicitly social type of imagination that complements the increased focus in science education research on the social aspect of imagination in the classroom, which we also discuss below.

2.1. Objectual imagination in HPS

Objectual imagination is the type of imagination that we intuitively associate with a "perception-like engagement with the [imagined] content in question" (Levy & Godfrey-Smith, 2020, p.6). This type of imagination is typically analysed with conceptual frameworks that draw explicitly on contemporary cognitive psychology[2]. We briefly mention the work of one influential author. Nancy Nersessian (e.g., 1992, 2007, 2008) has analysed the cognitive underpinning of conceptual change in science using the compelling notion of *mental modelling*: the imaginative manipulation of a mental analogue of a real-world object or phenomenon. Indicatively, Nersessian mentions that such "mental transformations are often accompanied by [for example] twisting and moving one's hands to represent rotation, which indicates motor as well as visual processing" (Nersessian, 2018, p.315). As mentioned below, such embodied aspects of the imagination are currently studied in science education.

There exists a noteworthy recurring link between HPS and science education research concerning objectual imagination. On multiple occasions, Nersessian has related her insights on scientists' conceptual development to the conceptual change that occurs when students learn scientific concepts:

> Clearly, one would expect differences between, for example, the practices used by scientists in constructing new concepts and students learning new (for them) concepts. For one thing, scientists have articulated theoretical goals and sophisticated metacognitive strategies while children and students do not. However, in conceptual change processes, a significant parallel is that each involves problem-solving. One way to think of learning science, for instance, is that students are engaged in (or need to be enticed into) trying to understand the extant scientific conceptualisation of a domain. In this process, learning happens when they perceive the inadequacies of their intuitive understandings - at least under certain conditions - and construct representations of the scientific concepts for them-

[2] We refrain from discussing the 'content' of objectual imagination because, to understate it, the 'exact character of the imagined content is up for dispute' (Meynell, 2014, p.4156). Many different frameworks for objectual imagination and further distinctions within objectual imagination are proposed; e.g., between imagistic and non-imagistic imagination—with little consensus in sight. Unfortunately, in-depth discussion is beyond the scope of this article. See, e.g., (Salis and Frigg, 2020, §1.4.1) for a brief discussion of various proposals.

selves. (Nersessian, 2007, p.392)

As an example of this relation, Sam Rijken mentioned in his talk at the workshop how an early publication on scientific thought experiments by Kuhn (1964) discusses conceptual change in two analogous contexts. First, young children who were subjected to Piaget's famous experiments, and, second, Aristotelians who were confronted with Galilei's thought experiments as elaborated in *Dialogue*[3]. Interestingly for the present discussion, Kuhn explicitly used insights from the former to better understand the latter, thus presenting us with a rare case of education research influencing HPS in a context relevant for the concept of imagination:

> The historical context within which actual thought experiments assist in the reformulation or readjustment of existing concepts is inevitably extraordinarily complex. I therefore begin with a simpler, because nonhistorical, example, choosing for the purpose a conceptual transposition induced in the laboratory by the brilliant Swiss child psychologist Jean Piaget. (Kuhn, 1977, p.243).

Kuhn points towards a problem for the systematic study of imagination in the context of scientific discovery: historical contexts are extraordinarily complex. To add to this complexity, we would like to emphasise that historians and philosophers of science do not generally have epistemic access to the imagination as employed by scientists in the context of discovery[4]. It is therefore an important question—worthy of future research—whether students' cognitive development in science education may serve as a *proxy* for scientists' cognitive development in the context of discovery; specifically the cognitive development that results from the use of imagination, as is the case for scientific thought experimenting. We will return to this question at the end of this article.

2.2 Propositional imagination in HPS

The second branch of HPS literature on imagination concerns so-called *propositional* imagination. As opposed to objectual imagination, propositional imagination is usually not understood as a perception-like engagement with some imagined content but rather as an imaginative, non-veridical attitude towards *propositions*: an attitude that is belief-like (because it typically mirrors belief-like inference patterns) but not quite belief (for multiple reasons, e.g., that imagination is voluntary, does not necessarily aim at truth, and does not directly guide real-world action)[5]. One example of propositional imagination that is currently remarkably popular in the HPS literature is *make-believe*.

'Make-believe' is a theoretical notion from Walton's (1990) conceptual framework for systematic acts of imagination that are prompted and constrained by the presence of material objects. Walton called these systematic acts of imagination *games of make-believe*. He originally formulated his framework to account for acts of imagination stimulated by representational art and works of literary fiction. Material objects constrain the ima-

[3] Kuhn restricts his discussion to 'an intermediate group [of children], old enough to learn something from the experiments and young enough so that its responses were not yet those of an adult.' (Kuhn, 1964, p.243).

[4] Only since very recently is the imagination being studied 'in the lab' (Stuart, 2019). Interestingly, Stuart notes that the 'idea of studying imagination using empirical methods' has been acted upon in recent science education research, see (Stuart, 2019, p.3) for references.

[5] For elaboration on the relation between scientific imagination (specifically, pretense) and belief, see, e.g., (Gendler, 2010, Ch.7; Salis and Frigg, 2020; Özgön and Schoonen, Forthcoming).

gination of participants of such games of make-believe due to the imposition of specific rules that determine what to imagine next: the *principles of generation*. Because these principles of generation include relevant background knowledge and social conventions, the imaginative content of a specific game of make-believe can be agreed upon inter-subjectively. Games of make-believe are, therefore, explicitly *social* acts of imagination. This social aspect of the scientific imagination has previously not been discussed much in HPS literature because the imagination is, in general, typically construed as a feature of individual cognition.

The principles of generation are a crucial component of games of make-believe: they enable communicating about imaginary content by fixing that content inter-subjectively. Nevertheless, it is far from clear what exactly all the relevant principles of generation are in a specific game, or even whether all relevant principles can always be formulated clearly. Much insight on this matter can be found by studying how children develop the capacity for make-believe. Remarkably, even very young children can engage in 'complex coordinated games of joint pretense with others. And well before the age of 4, they have figured out how to keep track of different individuals simultaneously engaging in different games of pretense [...] [and they] are extremely flexible and adaptive about the principles of generation we use when we engage in exercises of prop-based pretense' (Gendler, 2010, Ch.7). Presumably, research that looks at students and how they employ principles of generation in their imaginative acts —which in turn may bring about conceptual change— can provide bridging cases between games of make-believe played by young children and scientists.

Walton's games of make-believe and the construal of scientific imagination as make-believe have taken centre stage in HPS literature on scientific modelling in the past decade; e.g., (Frigg & Nguyen, 2020; Levy & Godfrey-Smith, 2020; Cassini & Redmond, 2021). Here, an important move has been to regard *model descriptions* as performing a significantly similar function as works of literary fiction do: model descriptions prescribe imaginings about some (imaginary) model system. The principles of generation play a significant role in determining the content of a scientific model, so this body of literature will most certainly benefit from an increased understanding of which principles of generation are involved in which games of make-believe - which science education research may provide. The notion of make-believe is also employed to account for the content of scientific thought experiments, and it is straightforwardly applicable to related topics concerning scientific imagination (c.f. Meynell, 2014; 2021). We believe, moreover, that the rise of make-believe in HPS is a promising development because make-believe's social aspect coheres well with a similar recent development on the notion of imagination in science education research.

2.3 Imagination in science education research

In parallel to developments in HPS, science education researchers have put increasing emphasis on the role of imagination in learning and doing science (e.g. Hadzigeorgiou, 2016; Kind & Kind, 2007; Steier & Kersting, 2019). Thought experiments, when presented correctly, are a powerful example of a pedagogical tool that invites the use of imagination. While thought experiments can serve as a stand-in for physical experiments that are too difficult or impossible to realise in the classroom, their true potential lies in connecting students' everyday experiences to implicit assumptions and abstract concepts. For this reason, thought experiments have proven to be a fruitful instructional tool in learning domains that deal with abstract and counterintuitive concepts, such as quantum mechanics and relativity (Velentzas & Halkia, 2012).

Although it seems clear that imagining constitutes an essential activity in science education practices, research still lacks a clear understanding of how students incorporate imagining into their classroom processes. Since classroom settings are socially active environments, it makes sense to consider imagining as a form of action—instead of a static feature of individual cognition (Hilppö et al., 2016; Murphy, 2004). A sociocultural stance to imagining allows researchers to study patterns of classroom participation as students engage in imaginative activities. For example, students may draw on words, gestures, material representations or other forms of publicly available signs when performing imaginative activities (Steier et al., 2019). From this perspective, science education researchers can treat imagining as one form of representation practices (Greeno & Hall, 1997). While such a sociocultural stance does not argue against the mental modelling often linked with imagination in the HPS literature, it does shift the focus to signs that teachers can recognise and build on to facilitate science learning.

Approaching scientific imagination from a sociocultural perspective has its roots in the work of developmental psychologist Lev Vygotsky (1998, 2004). Vygotsky proposed that imagination is an internalisation of play. When children play, they develop the ability to combine impressions and experiences from the world around them into something new that is not physically present - or might not even exist in the real world. Through play, children also adopt norms and rules of their society which feed into their imagination. In this context, Vygotsky understood imagination as the ability to think about the possible and not just the actual.

As children get older, their imagination matures and develops into a tool for meaningful creative action (Hadzigeorgiou, 2016; Vygotsky, 2004). Instead of merely dreaming or playing, students may use their knowledge and previous experiences to create something new and meaningful:

> (…) imagination is as necessary in geometry as it is in poetry. Everything that requires artistic transformation of reality, everything that is connected with interpretation and construction of something new, requires the indispensable participation of imagination (Vygotsky, 1998, p. 153).

There is a promising continuity between Vygotsky's approach to imagination from a sociocultural perspective and Walton's approach to imagination as a social act of make-believe, specifically in the emphasis on the rules and patterns that govern imaginative acts. This continuity has been somewhat explored recently in science education research (e.g., Reznitskaya & Gregory, 2013; Maynard, 2019), but interaction with recent developments of Waltonian approaches to the imagination in HPS is absent, yet clearly desirable. Here, contemporary science education research can inform HPS research by providing insights into the rules that govern acts of imagination gained through classroom studies.

Question 3: Looking forward

Finally, let us address the third question: what is required to make the respective insights from HPS and science education research into conceptual change of mutual benefit? In this article, we have examined how our joint engagement with conceptual change has led us to the topic of scientific imagination, and we have presented recent developments on scientific imagination in HPS and science education research. *To make these respective developments of mutual benefit, we now turn to two promising opportunities for fruitful interaction*. More generally, we argue that we need to move beyond the general theme of conceptual change and focus on specific topics, such as scientific imagination, and specific questions, such as the role of generation principles in imaginative interactions in science classrooms. Arguably, these topics and questions can only be answered comprehensively when HPS scholars and science education researchers combine their methods and insights.

The first opportunity for fruitful interaction is to explore the relation between the use of imagination in the scientist's context of discovery and the student's context of learning science. As mentioned in this article, these contexts have often been analysed in parallel, mainly for the purpose of applying newfound insights into the former to better understand the latter. However, given that imagination in the science classroom is now actively being studied, the question arises to what extent we may invert this flow of information. Can we study the scientific omi-imagination in the student's context of learning as a proxy for the scientist's context of discovery? We have indicated how HPS and science education research may find a common purpose and a shared terminology in Nersessian's account of conceptual change and her thoroughly developed notion of mental modelling. However, recent developments in HPS provide an alternative terminological framework that seems equally promising for this purpose.

The second opportunity for fruitful interaction centres on the concept of make-believe, a relatively new concept in HPS adapted from Walton's *games of make-believe* (1990). Games of make-believe are explicitly social acts of imagination. The fact that make-believe is currently taking centre stage in the HPS literature on imagination coheres well with the developments in science education research that stresses the importance of the socially active environment in which science students perform imaginative acts and communicate their understandings (Steier et al. 2019). We indicated the encouraging continuity between Vygotskyan approaches to the imagination in science education research and Waltonian games of make-believe in HPS, specifically in their focus on the rules that govern our acts of imagination in science research and education. Here, HPS and science education research may again find a common purpose and shared terminology that can further stimulate progress in both fields.

Finally, the question arises whether and how these two distinct possibilities for interaction between HPS and science education research can be realised. At this point, we do not wish to argue for specific ways in which this ought to be done. Instead, we invite colleagues to envision potential collaborations between HPS and science education that take their point of departure in shared questions and on the basis of knowledge gaps in both fields. We believe that progress will be achieved best if there is a shared vocabulary and focal point of research in the two disciplines, which, we have argued, can be found in contemporary approaches to the scientific imagination.

Conclusion

This workshop has shown that interactions between HPS and science education researchers can provide a good impetus for future research with mutual benefit. Having taken the topic of conceptual change as our joint starting point, we identified scientific imagination as a critical contemporary concept in both disciplines. To repeat, HPS has informed science education research quite a bit over the last few decades. We insist that this asymmetric relationship between the two disciplines limits progress on both sides. Therefore, we encourage scholars to investigate new ways in which field studies from 'within the classroom' may be informative for HPS. We believe that the scientific imagination is a contemporary concept that has great potential to stimulate fruitful interdisciplinary interactions in research on conceptual change and beyond.

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2022 sees the two-hundredth anniversary of the death of William Herschel, a profoundly significant figure in the field of astronomy, but one who made his early living as a musician - as an oboist, violinist, harpsichordist, organist, composer, and impresario.