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Imagination and Creativity in the Scientific Realm[1]

1. Introduction

Some of our go-to examples of highly creative and imaginative individuals, acts, and products come from the scientific realm. We might even regard science as the most impressive display of human creativity, due to its transformation of both our understanding of the natural world, and our ability to control and manipulate it, a view that Kidd (2021, 15) attributes to Marx.

Perhaps surprisingly then, imagination and creativity have traditionally occupied a peripheral position in philosophy of science. A distinction between 'context of discovery' (how new ideas are generated) and 'context of justification' (how such ideas are assessed) dominated philosophical discussions of scientific inquiry in the 20th-century. This led to the view that elements of discovery – including imagination and creativity – lie outside the proper scope of philosophy (Stokes 2016; Levy and Godfrey-Smith 2020). Hempel, for instance, stated "In his endeavor to find a solution to his problem the scientist may give free rein to his imagination, and the course of his creative thinking may be influenced by scientifically questionable notions." (1966, 16). According to this view, imagination and creativity may produce new theories or possible solutions but these are mysterious acts that cannot be subject to logical

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analysis. Further, such ideas need to face rigorous critical scrutiny in the context of justification before they are accepted, and it is the latter that philosophers ought to concern themselves with.

Thankfully, this view has been largely left behind. In the late 20th-century, accounts of the strategies involved in discovery challenged the idea that (scientific) creativity is unanalyzable, and that a sharp discovery/justification distinction can be made (Kuhn 1962; Nickles 1980; Schickore 2022). Moreover, the likes of Hesse and Polanyi urged philosophers to include "introspection, insight, and creativity" (Hesse 1971, 1) and "creative imagination" and "intuition" (Polanyi 1967, 111) in their logics of scientific discovery. More recently, there has been a surge of interest in imagination in science. Drawing from theories from philosophy of art and mind, philosophers of science have developed views on the role of imagination in theorizing, modelling, and the conduct of thought experiments. Given the epistemic goals of science, such examples offer fertile ground for those who seek to defend the claim that imagination can play a role in learning about the world.

The aim of this chapter is to explore imagination and creativity starting from issues within contemporary philosophy of science, making connections to these topics in other domains along the way. It discusses the recent literature on the role of imagination in models and thought experiments, and their comparison with fictions. It then turns to the importance of constraints on imaginings in the scientific domain, as well as whether constraints can hinder creativity. The second part of the paper focuses on the social dimensions of science. It considers imagination and creativity of scientific communities, asks whether the institution of science promotes creativity (and whether we want it to) or if it encourages conservativeness, and ends with a reflection on the politics of imagination and creativity in science.

2. Models, Thought Experiments, and Fiction

We can begin with the area in which the imagination in science has gained most attention: models. Given their widespread use across science, models are a central topic in philosophy of science. They are a diverse category. Some are material objects, such as ball-and-stick models of molecules. Others, our focus here, are theoretical, described by equations such as models of predator-prey interaction, or the Newtonian model of the solar system.[2] Theoretical models involve idealizing and simplifying assumptions – predator-prey models describe a system where only two species interact, and the Newtonian model describes the planets in the solar system as perfect spheres. These models thus depart from how predators and prey or planets in the solar system interact in reality, yet they allow scientists to learn and make predictions about these systems in the real world. This has prompted a vast literature regarding the ontology of models and their epistemic power.

One way to address these issues is to take seriously how scientists engage their imaginations to contemplate what a model describes. Advocates of the *fiction view* argue that engagement with scientific models is of the same mental kind as engagement with fictional artworks. While some offering different views on the ontology of models have also highlighted the importance of imagination and/or fiction (Weisberg 2013; French 2020a, 2020b; Thomasson 2020), a version of the fiction view that draws on Walton's theory of representation in philosophy of art is especially popular amongst those who emphasize imagination.

Defenders of the Waltonian view argue that model descriptions function as 'props' that guide imaginings. These prescriptions to imagine fix the content of the fictional world. Some of what is 'true in the fiction' are primary truths, stated explicitly in the description. Others are implied truths, derived from principles of generation such as the reality principle which authorizes the use of real-world facts to fill in the background world of the fiction. The practice of modelling

[2] For an overview of the literature on models, see Frigg and Hartmann (2020).

is a matter of finding out the implied truths of the scenario described, i.e., finding out what follows from the explicit prescriptions.

Waltonian accounts are split on the issue of how scientists gain knowledge of the world via modelling. According to indirect views (Frigg 2010), when scientists represent the world, they do so via a model system. E.g., the Newtonian model of the solar system prescribes us to imagine an idealized version of the real solar system. Once this model system imagined, and scientists learn new things about it, they can then translate facts about this to the target system, thereby learning about the actual solar system. In contrast, direct views (Toon 2012, 2016; Levy 2012, 2015) do not postulate a model system; models represent target systems directly. E.g., the Newtonian model prescribes us to imagine the actual solar system in a particular way; we imagine the planets and the sun as perfectly spherical etc. Levy (2015) suggests drawing on Yablo's (2014) concept of 'partial truth' to explain the way in which we can learn about the world on the direct view: rather than making a comparison between a model system and a target system, the truth of parts of a model is evaluated when interpreted about the real world system.[3] Salis (2020) connects these debates with the wider literature on learning from imagination, arguing that the Waltonian framework is suitable for imagination in science as it an instance of highly constrained imagination and it captures its social dimension (discussed below). This, Salis argues, makes it favorable over those views that center counterfactual conditionals (for debate, see Godfrey-Smith 2020; Salis and Frigg 2020; Williamson 2020).

A related practice is the use of scientific thought experiments. Thought experiments involve imagining a fictional scenario to work out what would happen if it occurred. They contribute

[3] The indirect view is said to capture how scientists talk about modelling and more easily accommodate 'targetless' models. The direct view is said to offer an account of how we learn from models that avoids ontological questions surrounding model systems. For debate see Friend (2020), Frigg and Nguyen (2020), and Salis (2020, 2021). Thomasson (2020) argues that an artifactualist view of fiction includes the benefits of the Waltonian theories whilst being able to accommodate more easily external, i.e., critical and historical, discourse about models qua fictions.

to the creation and development of novel theories, expose contradictions within or strange implications of existing ones, and have pedagogical value. Famous examples include Galileo's falling bodies, Maxwell's demon, and Schrödinger's cat, to name just a few. Like models, thought experiments are widely taken as bringing about knowledge of the world, though there are various conflicting accounts as to how they do so (see Brown 2004, 2007; Norton 2004; Gendler 2004; Stuart et al. 2018).

Given the similarities between thought experiments and models, the analyses above may carry over to how we learn through imagination in thought experiments. But alternate views have also been developed. Gendler (2004) argues that thought experiments are imaginary scenarios which produce 'quasi-sensory' intuitions. Not only can such mental images lead us to form new hypotheses, but they can also be reliable enough to carry justificatory force in the way that we can reliably imagine whether some piece of furniture could fit within our living room. Similarly, Sorensen (2016; 1992) compares the reasoning involved in thought experiments with more everyday uses of imagination and ordinary perception. On his view, the latter's reliability underwrites its capacity in scientific cases. However, doubts have been expressed regarding how far we should generalize from particular successful uses of imagination (Murphy 2022; Kinberg and Levy *forthcoming*).

This leads us to the following question: What exactly is meant by 'imagination' in models and thought experiments? The difference between propositional imagination – imagining *that* something is the case, with no mental imagery required – and imagistic imagination – forming (usually visual) mental images – is most discussed in the context of science. We might think that mental images are limited in the context of scientific models. How can we visualize statistical models that describe infinite degrees of freedom, or those that involve probabilistic elements? (Weisberg 2013; McLoone 2019; French 2020b). Motivated by this, some have argued that it is the propositional imagination only that is necessary for science. Mental images may accompany our imaginings, but these play no special role (Salis and Frigg 2020). However others maintain that visual mental imagery is (at least sometimes) necessary for modelling or for conducting thought experiments, or they adopt a pluralist view; different types of imagination work together in science (Gendler 2004; Arcangeli 2010; Murphy 2020; French 2020a; Nersessian 2007; Todd 2020; Meynell 2014).[4]

3. Imagination, Epistemic Value, and the Limits of Constraints

Imagination, whether imagistic or just propositional, is said to play an important role in gaining knowledge of the world. But what other epistemic goods can imagination deliver? And to what extent do we want to say that the imagination's epistemic power depends on the application of constraints?

Imagination is said to aid the acquisition of scientific understanding, often understood as distinctive from, and irreducible to, scientific knowledge (though see Baumberger et. al. 2016 for an overview of the debate). E.g., Maxwell's demon uses a thought experiment to demonstrate how a violation of the second law of thermodynamics is possible. We are asked to imagine a demon operating a door that separates a box of hot gas (with fast moving molecules) and a box of cold gas (with slower moving molecules). The demon can selectively open the door so that heat flows from the cold gas to the hot gas, making the hot side hotter,

[4] Further, some take it that thought experiments and models are very similar practices and one theory of scientific imagination can account for both (Salis and Frigg 2020; Frigg and Nguyen 2020). Others highlight their differences including those that arise from an analysis of their use of imagination (Murphy 2020). See also El Skaf and Stuart (forthcoming).

and the cold side colder. Through imagining the scenario, we come to understand that the law holds only at the statistical level (Stuart 2016).

Imagination is said to facilitate understanding of some phenomena through allowing us to explore ideas that unify it or to create connections between theory and our background knowledge of the world (Breitenbach 2020; Stuart 2017, 2018; Murphy 2023). Elgin states that scientific thought experiments facilitate understanding through the mechanism of exemplification, i.e., via isolating the properties of interest and focusing our attention on them, and argues that artworks can function in the same way (2014; 2017). Understanding is often said to require an extra factor in addition to knowing some set of propositions, namely, an ability to 'grasp' or 'see' how parts of a scientific model, say, fit together, as well as an ability to apply understanding to new cases (Riggs 2003; Grimm 2011; Stokes 2021; Zagzebski 2001). This language of 'seeing' might indicate that the imagistic imagination can aid understanding. For de Regt (2017), a grasp of the consequences of some theory in a concrete situation is at the core of gaining scientific understanding. Visualizing these consequences in our imagination is one way to achieve this (see also Meynell 2020; Murphy 2020; Todd 2020; Elgin 2017). In addition, Toon (2015) argues that understanding is not just 'in the head' but can extend to the body and external, material devices, opening the door to embodied imagination in science, an idea also present in Nersessian's (2007) account of thought experiments.

The application of constraints on our imagination is said to separate epistemically productive imaginings from 'transcendent' ones, e.g., those involved in fantasy and play (Kind and Kung, 2016). Stuart (2020) points to two kinds of constraints commonly discussed in the imagination literature: 'logic based' constraints that ensure our imaginings accord with the rules of good argumentation, and 'model based' constraints that ensure our imaginings involve an accurate representation of the system we are trying to learn about and the ways we manipulate this target system in our imagination tracks how it would change over time. While such views have demonstrated that despite its 'free' nature, imagination can be put to epistemic use, we might question whether accounts have successfully carved out a distinctive role for imagination in knowledge production (and we might extend this to other epistemic goods), or whether imagination is a mere 'arena' for the performance of ordinary inferential reasoning (Kinberg and Levy *forthcoming*). This view is implicit in Norton's (2004) analysis of scientific thought experiments in which their epistemic value is due to how well they function as an argument; their 'picturesque' qualities (including their narrative form and the imagery they evoke) are irrelevant.

While constraints are clearly important for productive uses of imagination, a further worry is that an emphasis on particular constraints will limit other creative uses of imagination. As Stuart (2020) details, scientists employ imagination in ways that break the constraints typically proposed. Notable instances include two of the most famous thought experiments in physics: Galileo's falling bodies and Einstein's light beam. Such constraint-breaking imaginings are not failures or mere flights of fancy; they are pivotal episodes in the history of science that led to new theories. Drawing on Feyerabend (1975), Stuart argues that such episodes impart important lessons about the dangers of dogmatism and the prospect of identifying an exceptionless set of constraints that ought to operate on imagination (2020, 975).[5]

4. Creative Communities, Imagining Together

[5] Similarly, Todd (2020) argues that the Waltonian fiction view cannot explain how scientists make novel discoveries, given that according to their analysis, constraints on imagination (and therefore, what can be derived from the principles of generation) are decided prior to engagement with them. Skolnick Weisberg (2020) argues that research in empirical psychology points to the ways in which our imaginings are largely grounded in how the world is but worries that this undercuts its creative potential.

We typically associate creativity with individual, brilliant, minds and regard imagination as a private, mental activity. Yet science is crucially a social practice, involving collaboration between individuals and groups of scientists. This gives rise to epistemological and ethical issues concerning testimony, trust, and expertise both amongst scientists and in their communication to the public. In emphasizing the social nature of the production of scientific knowledge, philosophers seek to dispel a prominent but misleading image of science in which it is lone geniuses with uniquely powerful imaginations that drive its progress (Shapin 1989; Gerken 2022). Despite what we've seen so far, we might ask: Does the collective nature of science limit the role that imagination and creativity can play in the scientific domain? While for the most part, theories of creativity and imagination have conducted their analysis at the level of the individual, the next two sections explore their place within the social dimensions of scientific practice.

While 'collective imagination' (see Wiltsher, this volume) is under-theorized in the context of science, one of the cited strengths of the Waltonian view as applied to scientific uses of imagination is that make-believe is a social, intersubjective activity, and consequently accommodates how modelling is embedded within a scientific community (Salis and Frigg 2020; Salis 2020; Molinari 2022). E.g., on the indirect view, some features of a model system will be indeterminate (say, the specific species in a predator-prey model) and there might be some differences in what individual scientists imagine when modelling. But it is not the case that scientists can freely choose to imagine anything that they would like to imagine when properly engaging with a model. Rather, model descriptions prescribe certain imaginings and hence limit what can be taken as true in the model system. In this way, modelling involves scientists imagining together i.e., within the same set of constraints. Another sense in which we can consider the social dimensions of imagination in science is via cases of adversarial imaginings. Disagreement amongst scientists and groups of scientists is regarded as potentially epistemically productive. We might similarly wonder about the fruitfulness of dissenting imaginings. E.g., scientists might imagine the initial setup described by a thought experiment but disagree about what would happen if it were to occur, or they might agree on the imagined phenomena, but disagree about what theoretical conclusions can be drawn (Brown 2007; Palmerino 2018). Such 'clashes' (Molinari 2022) in imagination can bring about modifications in thought experiments, result in their rejection, or prompt new theoretical work. Scientists thus engage in both collective imaginings and exchange opposing ones, offering a comparison with social imagination in the legal domain (see Del Mar, this volume) and in social movements (see Moody-Adams, this volume).

There is also some expression of the limits of an individualist approach to creativity. Feyerabend (1987) argues that scientists are not isolated individual agents but operate within a community (discussed in the next section), a particular social and historical context, and against a background tradition, and this should be taken into account by theories of creativity (see also Laudan 1978, chapter 3; Kidd 2021). The latter is emphasized by Hills and Bird's (2019) analysis of creativity as a disposition to generate varied novel ideas through imagination. They argue that scientists select possible solutions to problems in their imagination through analyzing their similarities to existing problems. Successful uses of imagination, i.e., ones that are likely to arrive at valuable solutions, are informed by tradition which "both constrains and guides the imagination's search through possibility space." (2019, 5).

This leads to another sense in which scientific creativity has been obscured. On the romantic view, creativity is mysterious and impossible to understand, and creative individuals are exceptional and naturally gifted. The upshot of this is that creativity is something that cannot be taught. Yet such claims have been resisted and there are now accounts of imagination and creativity as skills or as involving skills, i.e., abilities that can be taught and improved by practice (Gaut 2009; Kind 2020, this volume; Blomkvist 2022). Scientists' education and training therefore has the potential to guide, develop, and improve imagination and creativity. But philosophers and scientists have worried that it often hinders such capacities since it focuses largely on the learning of formal methods and encourages students to stick within narrow disciplinary standards. For these reasons, Feyerabend argued that science education "leads to a deterioration of intellectual capabilities, of the power of the imagination. It destroys the most precious gift of the young, their tremendous power of imagination" (1975, 96-7). In response, Martin (2008) and Stuart and Sargeant (forthcoming) have proposed ways in which creativity and imaginative thinking can be nurtured. This includes educators providing students with opportunities for more open-ended explorations that require imaginative engagement, such as designing their own experiments, as well as encouraging risk-taking. Furthermore, moving beyond text-book formulations of discoveries to instead present historical and personal details of important scientific episodes and exemplary scientists, as well as providing opportunities to witness science as practiced early on in their education, will expose students and scientists-in-training to the character traits of creative scientists which they can then strive to emulate. More radical suggestions can be found in the work of quantum physicist Bohm (2014) who suggests that scientific creativity can be aided through an engagement with different philosophical traditions such as Indian philosophy and via collaborating with artists, both of which help broaden the landscape of conceptual possibilities.

There are various ways, then, in which we can resist problematic assumptions regarding imagination and creativity that renders them capacities limited to gifted individuals. But are scientific communities organized in a way that fosters creativity? If so, is this good for scientific progress?

The tensions between a want for trustworthy, well-confirmed, ‘conservative’ science versus ground-breaking, risky, ‘creative’ science are present in a debate between Kuhn and Popper (Currie, 2019a). For Popper, good scientists create generate bold new theories in their imagination and then put them to the test. Whereas for Kuhn, scientists should be in the business of applying and developing pre-existing methods and theories, particularly in periods of ‘normal’, i.e., non-revolutionary science. Popper (1970, 52) regards Kuhn’s view of a scientist as someone we “should be sorry for”, a “victim of indoctrination” and lacking in the critical attitude needed for good science. Kuhn’s response is that the idea that a scientist “should at all times be a critic and a proliferator of alternative theories” is incorrect; this should be saved for “special occasions.” (Kuhn 1970, 243).

Yet, as Rowbottom points out, Popper and Kuhn consider the desirable attributes of each individual scientist. But if we consider science at the group level and focus instead on the features a scientific community should display, then we might find that the inclusion of both types of scientist is optimal. Currie (2019a, 2019b) makes an explicit connection between these ideas and the creativity literature. Following Boden (2004), Currie understands creativity in terms of the exploration of some possibility space. In ‘creative’ explorations, scientists put less weight on their expectations, opting for something that hasn’t been tried before or failed in the past. These are taken up by ‘mavericks’; the explorations are more likely to fail and the results less likely to be published but would be highly rewarded if successful. ‘Followers’ opt for less risky procedures, exploring solutions closer to standard procedures, and make incremental progress.

For Currie, scientific communities ought to include mavericks whose creativity is especially needed in certain contexts, e.g., in research projects aimed at learning about unique, unprecedented phenomena, where there are no well-established models and theories to draw upon. Currie offers one way to think about the creativity of scientists as a group – it ought to be distributed differently depending on the requirements of a given field or research project.

A potential further way to capture collective creativity in science involves aligning these ideas with the five-stage model of creativity proposed by Paul and Stokes (2023, section 5), consisting of Preparation, Generation, Insight, Evaluation, and Externalization. With this in play, we can see that the 'maverick' qualities that Currie highlights ought not be directly equated with creativity itself. Instead, they align more closely with the generation stage, which involves the production of new ideas, and perhaps also the insight stage, i.e., the feeling of a new idea, often characterized as the 'eureka' moment. This would allow for the other stages of creativity – especially the preparation stage in which scientific expertise is acquired and the evaluation stage in which the new idea is assessed – to be more spread out amongst the scientific community and including those labelled as 'conservative'. Thus, an additional way to understand collective creativity is through examining the division of creative labor in science. This perspective acknowledges that often, no one individual is responsible for all stages of the creative process and that genuine creativity emerges at the group level.

A final way in which the tensions between creative and conservative science emerge is through reflections on the reward structure of science. As Strevens puts it, science is a "winner-takes-all race." (2003, 56). Credit, in the form of prestige and prizes, is rewarded to those who discover first. The way in which scientific creativity can lead to independent discoveries of the same theory or phenomena, as in the case of Darwin and Wallace's separate discoveries of natural selection, is cited as a difference between creativity in science and in art (Gaut 2010, 1039). Perhaps there are some cases where two people were credited as historically-creative for some discovery, but for the most part, those who discover second or third and so on, no matter how close a race, are not rewarded. On the one hand, the reward structure of science is seen to encourage novelty but at the expense of good, well-confirmed science. Heesen (2018) argues that it incentivizes scientists to publish their work quickly, and disincentivizes them to replicate experiments, contributing to the reproducibility crisis. Martin (2008) sets out how desire for creativity and recognition, reinforced by pressures from funding bodies, can lead to scientific misconduct. As Merton states, "Competition in the realm of science, intensified by the great emphasis on original and significant discoveries, may occasionally generate incentives for eclipsing rivals by illicit or dubious means." (1957, 651).

On the other hand, the ways in which contemporary science is structured has been regarded as stifling creativity. Features such as the professionalization of science, the introduction of peer-reviewed funding, and the rise of 'Big Science' – where large groups of scientists collaborate on common research projects – have "served to reduce not only the incentives but also the freedom scientists have to pursue research that challenges existing theoretical orthodoxy or seeks to develop fundamental theoretical innovation." (Stanford 2015, 7). This reduces creativity by producing a more theoretically homogenous research community and has encouraged funding of projects that are less exploratory, with more of a guarantee of success (Currie 2019b, 42).

It is therefore important to recognize how scientific imagination and creativity are institutionalized, i.e., shaped by shared norms that get passed on through scientific practice and cultivated (or limited) by scientists' training and education, and by the structures governing its practice.

5. Imagination, Creativity, and the Social Order of Science

This section continues the focus on the scientific community and explores the various ways in which the social order of science impacts imagination and creativity in science as well as the recognition of imaginative and creative agents.

To begin with, we can ask: Whose creativity gets recognized? As discussed, science is often depicted as individualistic, involving a lone figure's creative insights. Shapin (1989), Wylie (2015), and Anscomb (2020) outline the ways in which the labor of technicians, preparators, and other assistants who aid practices such as experimentation and fossil preparation is often ignored, rendering them invisible. While it is acknowledged that their contributions require practical skill, assistants are ultimately regarded as merely following directions or implementing routine procedures. In contrast, the scientists are seen as responsible for the creative, intellectual, knowledge-generating aspects of the project. Consequently, the labor of technicians is regarded as less valuable, and the workers themselves as replaceable, rather than creative in their own right. Yet this obscures the realities of collaborative work. Assistants in science (as well as in collective practices in art) can, and do, exercise what Anscomb labels 'creative agency' and thus ought to receive creative credit. Anscomb argues how assistants can be responsible for determining some of the salient features of some product (whether epistemic, as in the case of science, or aesthetic, as in the case of art) and the processes that are necessary for bringing about these features. Boyle's assistant Papin, for example, designed and constructed instruments used in Boyle's experiments, which he also planned and interpreted the results of (Shapin 1989, 559). Importantly, creative agency involves not merely executing some previously chosen method but an element of spontaneity (Anscomb 2020, 18; see also Kronfeldner 2009; Gaut 2018; Chung 2022).

A further consideration are the deeply entrenched stereotypes that operate around creativity. The concept of creativity, especially the romantic notion of the creative genius, has historically had a narrow application; limited to powerful men (Korsmeyer and Weiser 2021). Empirical studies have found that 'genius' is perceived as male (Elmore and Luna-Lucero 2017) and that women postgraduate students are less likely to enter academic fields regarded as requiring genius (seen as an inherent capacity) such as physics, mathematics, and philosophy (Leslie et al. 2015). There are also incidents of women's creative contributions being significantly downplayed or ignored entirely in accounts of scientific discovery, a classic case being the use of Rosalind Franklin's X-ray Photograph 51 in Watson and Crick's Nobel Prize winning discovery of the structure of DNA. Not only was the photograph – which displayed the double-helix structure of DNA – used without Franklin's knowledge or permission, the findings were published without any mention of her work.

Sometimes, then, the social order of science affects whose work gets recognized as creative and subsequently, deemed worthy of merit. It can also impact scientists' own attitudes towards creativity and imagination in science, including the value of their own creative and imaginative capacities. Interviews with scientists working in biology laboratories revealed some surprising trends: scientists more advanced in their careers spoke more positively of their use of imagination in their work, as well of the importance of imagination more generally, than those more junior (Stuart 2019). Furthermore, scientists belonging to marginalized groups are more critical of their own imaginative capacities, feeling less confident of its reliability and significance in science (Stuart and Sargeant, *forthcoming*). The authors focus on the important ethical implications of this difference in uses of imagination across different groups, also noting how this effects the degree to which members of marginalized groups can exercise creative agency.

Given that feminist studies of science have, for a long time, highlighted how scientific knowledge is hindered when marginalized perspectives are ignored or left out, we might also think that there is an epistemic upshot to the discrepancy that Stuart and Sargeant bring to the fore. To appreciate this, we can consider again the types of constraints that operate on the imagination.

We saw that those who defend the epistemic value of imagination emphasize that the imagination must be constrained if it is to be reliable. Usually, such accounts are concerned with the limits that we choose to put on our imagination, but our imagination can also be constrained in ways that we do not control, such as those that arise from the bodies we have (see Clavel-Vázquez and Clavel-Vázquez, this volume) or in experiences of imaginative resistance, specifically those characterized as an inability, rather than an unwillingness, to imagine. While imaginative resistance is usually discussed in the context of being invited to imagine morally deviant propositions as true, there is some discussion of how imaginative resistance also occurs in instances of trying to imagine counter-descriptive scenarios (Yablo 2002; Kim et al. 2018). Savojardo (2022) argues that one function of scientific thought experiments is to help overcome imaginative resistance by providing a 'bridge' between theory and our background knowledge and experiences (see also Stuart 2017). E.g., Darwin's thought experiments enabled his readers to comprehend how the theory of evolution by natural selection could account for various natural phenomena by providing visualizable descriptions of the alterations an organ or a species can undergo, resulting in large change over time. Here, I want to point to a further type of constraint that may operate (involuntarily) on imagination. This type of constraint is related to the social location of the imaginer, i.e., to features such as their gender and/or race.

Solomon (2009) links philosophical perspectives on creativity with a prominent strand of feminist epistemology: standpoint theory. Simply put, standpoint theorists hold that those who are marginalized or oppressed can have epistemic goods that those in power, or in relatively privileged positions, lack (Haraway 1988; Harding 1992; Collins 1986, 1990; Wylie 2003; Toole 2022). This epistemic advantage is not automatic but is instead actively achieved through practices such as consciousness raising. Standpoint epistemology is relevant to the sciences: the standpoints of marginalized groups can, e.g., expose sexist and racist values present in theories that obscure reality and might otherwise go unnoticed, provide explanandum or research agendas that contrast with those that arise from dominant, androcentric, epistemological frameworks, and lead to more objective science by allowing for an assessment of how likely the knowledge produced by particular knowers will fail to maximize epistemic virtues such as empirical adequacy, internal coherence, and explanatory power. As Wylie (2003) argues, this epistemic advantage should not be understood as applying across the board; it is local to certain areas of scientific research.

In developing these views, Solomon argues, standpoint theorists have been engaging with the topic of creativity for decades, though not explicitly. Those who have a marginalized standpoint might have traits that we typically associate with creative individuals. This includes being highly driven, critical of others' and one's own work, and possessing an "outsider" status, a trait of many creative people (Solomon 2009, 230; Gardner 1993). In science, the status of an 'outsider within' is perhaps most apt. Coined by Collins in the context of Black women in sociology, the term captures the 'double vision' of marginalized groups and the epistemic advantage this can confer. Black feminist sociologists, Hills argues, are both 'insiders' – trained scientists, experts in their field – and 'outsiders' – Black women in a male- and white-dominated profession, and thus are more likely to see problematic values embedded in their field and to question what dominant groups take as basic assumptions of sociology. Collins argues that Black women have "made creative use" of their status (1986, 14) offering novel critiques of sociological theories, e.g., by centering the lives of Black women in society and thus resisting the norm of generalizing from studies of white men to all other groups or from white women to all women, by challenging distorted descriptions of Black women, and by demonstrating the inadequacy of theories about workers that do not appreciate the interlocking nature of gender, race, and class oppression.

Conclusion

While imagination and creativity have often been left to the fringes of philosophy of science, this chapter has illustrated their significance in enhancing our comprehension of central issues within the discipline. These include the epistemology of models and thought experiments, the configuration of incentive structures in science, and scientific pedagogy and training. These discussions have initiated productive exchanges among philosophers of science, philosophers of art and fiction, and social epistemologists. This sparks optimism for increased interdisciplinary collaboration, as the potential benefits are only beginning to be seen.

I hope to have indicated that such benefits extend to not only philosophers of science, but also for those interested in imagination and creativity in epistemic contexts more broadly, as well as notions of collective imagination and creativity. As the final two sections of the chapter highlight, developments in social epistemology and feminist studies of science underscore the necessity of investigating beyond psychological features of individual agents such as possessing "maverick" styles of thinking or being highly driven. Instead, we must also investigate the impact of social structures and material conditions on abilities to imagine and to produce creative outputs, both within the scientific domain and beyond.

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