Introduction to the Volume

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1. Introduction

Aesthetic judgments feature prominently in scientific practice. Scientific theories are often compared to works of art, with scientists likening the process of constructing a theory to that of creating art pieces and even in choosing one theory over another they may invoke aesthetic considerations. Given these features of scientific practice, the questions naturally arise: What are the inter-relationships between aesthetics and science? How can the role of aesthetic judgments in scientific practice be justified? This volume engages with these questions and considers in detail the status of various features of such practice from an aesthetics related perspective, including thought experiments and models, visual aids and representations, together with the role of aesthetic considerations in the context of discovery and justification of theories, the experiences of beauty and the sublime in science and how they affect and shape scientific practice, and the nature of scientific creativity and imagination in general.

2. History of Engagement

Engaging in the *aesthetics* of science has certainly not always been a topic of pursuit in philosophy of science. During the positivist dominated years aesthetics and science were kept apart, and there was little value seen in the engagement between the two disciplines. For one, aesthetic considerations, if indeed relevant to science, were deemed to be psychological and subjective in nature, and though they might be employed in the process by which scientists come up with ideas, they were regarded to have no bearing upon the formal properties of the theory, that is, how the theory

relates to the world. Hans Reichenbach's famous distinction between the context of discovery and the context of justification conveys exactly this point: it is irrelevant how scientists come up with new ideas, whether they dream them up in their sleep or have a sudden illumination whilst taking a stroll, what matters is whether the reasons used can justify one's belief that the theory corresponds to the world. Reichenbach claimed that "It would be a vain attempt to construct a theory of knowledge which is at the same time logically complete and in strict correspondence with the psychological process of thought" (1938: 5). Thus, from the time of the Vienna Circle through to recent years, aesthetic considerations were not the focus of philosophical work. If acknowledged at all as featuring in the practise of science, such considerations were clearly demoted to the context of discovery, rendering them not part of the rational justification of scientific theories.

3.The Significance of Representation

Certain philosophical developments over the last decades have paved the way for departing from the constraints of Reichenbach's distinction and engaging systematically with the relationship between aesthetics and science. One contributing factor has been the popularity of the semantic approach to scientific theories and the increased interest in the function of scientific models. While the syntactic approach that dominated the years of logical positivism took theories to be sets of propositions that are truth apt, the alternative semantic, or model-theoretic approach, as famously outlined by Patrick Suppes (1960), introduced the notion of representation as the aim of theories. How theories represent the world became the central question, with many commentators drawing analogies with the representational nature of artworks and scientific theories explicitly compared to such artworks. Bas van Fraassen's (2008)

seminal work *Scientific Representation* engaged systematically with the notion of representation in art and in science, and the edited collection by Frigg and Hunter (2010) *From Mimesis to Representation*, further explored the relationship between scientific models and works of fiction. The recent volume *Thinking about Science, Reflecting on Art: Bringing Aesthetics and Philosophy of Science Together* (2017), edited by Bueno, et.al., gave additional momentum to this engagement, opening further avenues for exploration such as the act of interpretation in art and science and the question of whether there can there be a science of aesthetics. Further connections between art and science were also introduced in the work of Catherine Elgin (1991) and others, who compared literary works to thought experiments, showing how our understanding can be advanced through notions such as exemplification, for example.

4. Beauty in Science

Beyond the notion of representation and the comparison of scientific products such as theories and thought experiments to artworks, philosophers of science have also focused on the notion of beauty itself. The work of James McAllister, *Beauty and Revolutions in Science,* set the stage for understanding the notion of beauty within the historical evolution of scientific theories. It offered an account of how scientists come to form aesthetic judgments and how their training affects their aesthetic appreciation. McAllister also provided a justification for the idea that aesthetic considerations can play an epistemic role. While many scientific realists, contemporary and past, have tried to identify the theoretical virtues that correlate with the truthlikeness of theories, McAllister and others after him explicitly recognised that these virtues are often conveyed in aesthetic terms and noted that scientists explicitly use aesthetic language when they appraise them, recognising the need to give an account of the aesthetic

aspect of these judgements. Recent developments have seen a renewed appreciation for the role of certain values in theory choice and the development of scientific theories, as exemplified in Samuel Schindler's (2018) *Theoretical Virtues in Science: Uncovering Reality Through Theory*. Furthermore, there is further recognition that when scientists engage with theories that they consider beautiful they are indeed reporting genuine aesthetic experiences (Ivanova (2017)).

5. Science and Creativity

In addition to these emphases on representation and aesthetic qualities, historians of science, psychologists and neuroscientists have become invested in understanding the notion of creativity. Historians try to understand how scientists of the past came up with the new theories that revolutionalised their fields, psychologists try to understand what traits creative people have in common and how such traits are formed, while neuroscientists have focused on understanding the neurological functions involved in the exhibition of creative behaviour. The departure from the 'inspirationalist' accounts of creativity, which deemed inspiration to be a mysterious process available only to a select set of individuals, the 'great minds', has opened the door to the exploration of the creativity and the imagination in terms of computation, as advanced in the work of Margaret Boden. Here again the connection between art and science has become apparent, with creativity being highly valued in both the domain of art and the domain of science.

6. From Aesthetics to Philosophy of Science (and Back Again)

This volume extends this increased engagement between aesthetics and science of recent years and introduces new avenues for exploration. The collection focuses on

the status of aesthetic judgments with regard to the products of science, the status of scientific theories seen as constructions of scientific imagination, the experience of beauty but also the sublime in science, how aesthetic considerations inform and shape our activities and aims in science and, finally, the question of scientific creativity. There are important dimensions to science practice whose nature departs from the logical positivist's recipe of 'logic and experience', both in the context of discovery and justification, and entering the field of aesthetics, that need to be systematically explored. For one, scientists often make explicit aesthetic judgments with regard to the objects they study, the products of their activities as well as those very activities seem to be guided by aesthetic values. The phenomena studied in science are claimed to be beautiful, such as the diffraction of light rays or solar eclipses. More significantly, we find claims that the products of scientists' activities themselves exemplify aesthetic values, with physicists typically claiming theories such as Einstein's relativity theory or Newton's mechanics to be beautiful, Rutherford's experiments on the atom to be beautiful, Watson, Crick and Franklin's double helix model of DNA molecules to be beautiful and so on. And the very construction of a theory or an experiment can be claimed to be guided by aesthetic considerations. Since aesthetic judgements enter in all these levels of theorising, there is a need to understand the nature of these aesthetic judgments and the role they play. What are the set of aesthetic judgments that guide scientists? Are they fixed once and for all, and across disciplines, or are they largely contingent, relevant to a framework, school of thought and time period?

Debates in aesthetics have aimed to resolve the very same question when it comes to artworks. According to objectivism, aesthetic judgements have validity across individuals, time frameworks and societies, meaning that there is a fact of the

matter whether a certain object is beautiful or not. Objectivists argue that aesthetic judgments can be regarded as independent of subjective taste and fashions and point to works of art that have continuously been appreciated cross culturally and through time. For instance, we value the works of Callicrates, Polykleitos and Homer today as they were valued in antiquity, supporting the idea that our aesthetic judgments are objective and do not change with time or across societies. On the other hand, some artworks can initially be regarded as 'ugly' or aesthetically displeasing, but gain ground later, suggesting that aesthetic judgements can be subjective, contingent and varying across time, communities and individuals. The infamous reception of the Eiffel tower exemplifies this point. Most artists and architects in the 19th century wanted the tower demolished, calling it a 'monstrosity' over the Parisian skyline, but only a decade later the tower became a symbol of modern architecture and regarded as one of the most beautiful buildings in the world. Similarly in science, some values seem to gain ground after they are introduced in the scientific community. For instance, symmetry was not praised before relativity theory, elegance was irrelevant before the mathematical formalisation of theories, culuminating with Newton's development of the calculus and his theory of gravity. What shapes the community's response to aesthetic qualities of theories and what roles these can play are questions that are beginning to receive more systematic attention in the contemporary literature.

Another aspect of productive engagement between aesthetics and philosophy of science concerns creativity and the imagination. We value original ideas and the creative process responsible for their generation. When it comes to artworks, we do not ascribe value to copies or forgeries; we value originals. In science, we praise and admire those who discover new theories, phenomena and design new experiments or instruments, those who produce new proofs rather than whose scientists who replicate

experiments, come up with a theory second or third. The reward structure in science reflects this phenomenon; credit attribution goes to those who discover first. We grant Nobel Prizes for new discoveries, while not much value is given to those who replicate experiments, for instance, leading to problems such as the replication crisis (Heesen (2018)). As the sociologist Robert Merton reflected, science is governed by the priority rule, the fight to be the first who comes up with new ideas. How do artists and scientists do this?

Galileo, Newton, Curie, Einstein and Poincare are the usual examples given of creative minds, geniuses raised to the status of mythical superheroes endowed with creativity and imagination that transformed the field and our understanding of the world. But was there anything special about these scientists? Creativity has been the focus of much attention in aesthetics. Earlier 'inspirationalist' accounts took creativity to be due to divine or special inspiration available to very few individuals, but more recently systematic work in psychology and neuroscience has illuminated the creative process and the social and cultural aspects that enable some individuals to develop creativity. In the work of Boden (2004) and others creativity is understood as the exploration of conceptual spaces and the ability to connect already known ideas, with value being ascribed only to those connections that are historically novel. Within this new way of thinking about creativity, interesting questions arise, such as whether creative individuals share the same traits, how creativity can be cultivated, and how an individual's environment, social and cultural background and resources available them can affect that creativity. This also generates questions regarding credit distribution and recognition that creativity could be explored from the perspective of groups rather than individuals (Curie (2019)). Interesting new dimensions in the study of creativity has also recently been raised in the work of virtue epistemology, where

creativity is construed as an epistemic virtue whose instantiation in an individual leads to epistemic success. A troubling issue for virtue epistemology is to reconcile the descriptive and normative aspect: as a matter of fact, biographical accounts often reveal that creative people exemplify a lot of epistemic vice, from self-centeredness, dogmatism and ego-centric bias, to egotism and narcissism. How are we to reconcile the idea of the virtuous knower with the descriptive aspect that new revolutionary ideas that lead to scientific progress and epistemic success are a product of epistemic vice? The problem opens the door to reconsidering the notion of creativity within both virtue and social epistemology and exploring the creative process from the dimension of groups and individuals.

The new engagement between philosophers of science and aesthetics has also motivated work in the history of philosophy of science and the search for ideas that predate the logical positivist distinction between the contexts of discovery and justification. Here philosophers have uncovered interesting work on aesthetic aspects of science developed before or during the logical positivist movement, from Dirac's arguments on beauty by Graham Farmelo, to Praisly Livingston's revival of Poincare's sophisticated account of creativity and scientific discovery, to David Stump's revival of Pierre Duhem's use of 'good sense' in theory choice and Milena Ivanova's recent reconstruction of Poincare's account of beauty in science. These works shows that there was a systematic engagement in the early 20th century with the notion of creativity in the context of scientific discovery, the notion of beauty as a guide and evaluator in scientific reasoning, and the role of aesthetic sensibility in scientific decision making, all of which can be productively reintroduced into our contemporary engagement in this field.

As two of the contributors to this volume, Arcangeli and Dokic, note, '[a]esthetics seems to enter science on at least three different levels:

(i) The *objects* of scientific enquiry (such as cells, mu-mesons, and numbers) may instantiate aesthetic values.

(ii) The *products* of science (such as theories, conjectures, and models) may instantiate aesthetic values.

(iii) The scientific *practice* (such as constructing and evaluating theories, and designing experiments) may be guided by aesthetic experiences and judgements.'

The contributions in this book focus primarily on ii) and iii), the products or 'outputs' of science, including not just theories and models but also thought experiments, for example and the practices, covering, in addition to theory discovery and justification, the presentation of theories at lectures and seminars, for example. We'll also look at the practitioners of science, not just in terms of what they do and produce but the virtues and vices that they exhibit. In doing so we shall address various aspects of the above issues from a variety of perspectives that, we hope, will further advance the engagement between aesthetics and philosophy of science in general.

7. Summary of Contributions

In the opening contribution to the volume, Catherine Elgin addresses head-on 'the problem of the aesthetic' in the context of science: is there any epistemically good reason to prefer a theory that possess certain aesthetic qualities to one that does not? And what are we focussing on when we make such assessments? Extending a view found in the philosophy of art, Elgin suggests that aesthetic responses to theories consist in the apprehension and appreciation of 'scientifically significant forms in a logical space', where the nature of these forms is context dependent. Furthermore, she

argues, the role of the relevant aesthetic factors is not merely instrumental nor is it truth-conducive; rather these factors act as 'gatekeepers' on the acceptability of theories. In her earlier work she has developed the view that an understanding of a given topic consists of a systematically linked body of information in reflective equilibrium that is grounded in fact, is responsive to evidence and enables non-trivial inference and argument about a range of phenomena. And insofar as an aesthetic factor is ineliminably integral to such a network of scientific commitments, then it is epistemically justified.

Thus she considers the role of symmetry in modern science, regarded as an aesthetically pleasing feature. The recent history of physics demonstrates how scientists prefer symmetry-preserving theories and this preference clearly affects their behaviour in accepting or rejecting new hypotheses or results in general. Another factor is systematicity; as she puts it, '[w]e want our fabric of scientific commitments to be tightly woven.' Yet another is simplicity, notoriously complicated as she points out. Different kinds of simplicity may be traded off against one another and come to the fore in different contexts. Nevertheless, construing it as an aesthetic factor helps explain scientists' preferences for simpler theories and models.

As she goes on to note, such aesthetic considerations may be initially tenable and thereby constrain future theorising. Candidate theories that display these qualities will be deemed to be acceptable over those that do not. However, every component of that systematic body of information in equilibrium is up for grabs and it may of course turn out that the cost of insisting on a particular quality is too high, so that its scope must be reduced or it is abandoned altogether. Conversely, a particular factor may gain in importance, as in the case of symmetry in the shift from classical to

quantum physics. Thus aesthetic factors play a regulatory role, helping to shape our accounts and frame our understanding.

The way in which the aesthetic features of scientific theories and models contribute to the understanding associated with them is one of the themes running through a number of the contributions. In her 'Getting the picture: Towards a new account of scientific understanding', Letitia Meynell connects recent work on the nature of scientific understanding with these aesthetic features of science by advancing her 'pictorial' account of the former. According to this, the characteristic content of understanding is pictorial rather than propositional and it is by virtue of the epistemic flexibility of pictures, that, Meynell claims, her account can embrace unificatory, mechanistic and pluralist views of understanding. Two features of pictures are key to their exemplification of the cognitive processes and values characteristic of understanding: first, their affinity to visual experiences via their two-dimensional character. It is through this feature that the unificatory aspect of understanding can be accommodated, as the relevant aspects under study are brought together into as whole by the viewer. And insofar as there will be a range of legitimate ways of reading an image, this account can also capture the way in which understanding comes in degrees.

The second feature concerns their representational role, in which they serve as props for the imagination. In this respect de Regt's emphasis on visualisation can be accommodated, but so can Woodward's and Salmon's causal theory, since the causal basis of our visual experience of reality will be carried over to our comprehension of pictures that represent the relevant states of affairs through their spatial features.

Meynell further draws on Walton's work in aesthetics to argue that different people may possess different understandings of, say, a genetic ribbon diagram by

virtue of bringing to bear a different array of beliefs, habits of mind, conventions and so forth – that Walton calls 'principles of generation' – that constrain but do not determine what is to be imagined and under what circumstances. Given the distinction between the system under study or the artwork and the viewer's experience of it, this can then account for how different viewers may have different understandings of the same work, which further illuminates the differences between subjective and inter-subjective understanding in science.

To illustrate her account, Meynell draws on her previous work on Feynman diagrams, arguing that they help to unify the relevant phenomena in a cognitively accessible way, display complex causal connections within those phenomena and allow scientists to bring their own interests and commitments to bear on the interpretation of quantum field theory. She also considers the understanding required to give informed consent in research, arguing that this involves not only the acquisition of relevant information but the integration of various different types in a way that accommodates how participation may cause various complications for the participant as well as the positive outcomes. As she notes, this can be compared with Elgin and Goodman's 'world-making' and although this isn't the same as understanding the research itself it does involve at least a rough sketch of the science in question and some grasp of what participation in the research will imply. Through such examples Meynell elegantly weaves together themes from aesthetics and philosophy of science to lay down the basis of a more nuanced account of understanding across both domains.

Todd also considers the role of imagery in science but adopts a different tack. Focussing on imagistic imagination or 'visualisation' in thought experiments and scientific models, he rejects recent 'fictionalist' accounts of these outputs of scientific

activity that draw on Walton's work. The problem he finds with the Waltonian account of fictional engagement is that for thought experiments and models to play the roles that they do in scientific practice, certain constraints need to be applied, yet the account is notably lacking in detail as to the nature and origin of these constraints. Ultimately, he insists, we must look elsewhere if we are to shed any light on the cognitive value of thought experiments and models and on the epistemic function of imagination that is involved.

Underpinning such accounts, he suggests, is a view of imagery that takes it to be epistemically useless. And this in turn is grounded in the idea that imagery is 'transparent', in the sense that although we may employ images to help us imagine, we see through them the things we are actually imagining, as it were. However, he argues, when we have an imaginative experience, there are certain phenomenological and structural features of that experience that we are aware of, simply in virtue of having it. Indeed, it is the relative 'opacity' of imagery that leads it to play a significant cognitive role in scientific reasoning.

Indeed, he goes on to suggest, imagery might possess important cognitive value arising from its connection with certain affective states that themselves possess cognitive import. The imaginative contemplation of certain thought experiments may evoke certain quasi-sensory intuitions on the basis of which new beliefs can be formed. More generally, there are broader connections between imagery and affect that support a more expanded role to imagery when it comes to scientific models. In such cases, certain salient aspects are highlighted, and certain patters recognised through the engagement with imagistic imaginings and this derives from the deep connection between imagery and aesthetic feelings and the epistemic function that the latter serve in scientific reasoning.

Two such are the ‘feeling of knowing’ that has to do with the accessibility of the knowledge that one has, and the ‘feeling of understanding’ that concerns the intellectual satisfaction that motivates the endorsement of a scientific explanation. As Todd notes, there exists evidence for neural correlates of these feelings, and also support for the claim that some epistemic feelings do play a justificatory role in accurately predicting future cognitive performance, as well as in acting as a stimulus to judgement. These feelings of knowledge and understanding play a central role in scientific reasoning and in the development and application of scientific models but, as Todd has argued elsewhere, we can also regard them as possessing aesthetic attributes. Thus they are ‘valenced’, whether positively or negatively, they are typically ‘quick and dirty’ responses that are opaque in certain ways and, crucially, they are often characterised as aesthetic in scientific practice. Furthermore, when it comes to ‘understanding’ and ‘fit’ we find striking continuities between aesthetic judgments and scientific ones, in terms of in terms of the appreciation of patterns, connections, symmetries and harmonies in each case. The kind of understanding that is involved here, Todd argues, is not primarily propositional – it is imagistic, affective and, crucially, typically has an aesthetic character.

As he says in conclusion, in those cases in scientific practice for which visualisation and imagery are unavoidable, they are typically accompanied by feelings that arise from the phenomenal character of the imagining itself. And the feeling associated with understanding or ‘fit’ in such cases is not that whichg could be associated with some passive perceptual or belief state. Rather, there is conscious effort involved in such cases that manifests in aesthetic-epistemic feelings tied to the kinds of features that are examined from different perspectives in this volume; that is, features such as harmony, unity, symmetry and so forth.

Understanding also features prominently in Ivanova's contribution, where she argues against accounts that seek to relate the aesthetic qualities of a scientific theory to its likelihood of being *true* and maintains, instead, that aesthetic factors are tightly bound up with our own cognitive make up and the desire to understand the world around us. As she notes, beauty, whether exemplified by the elegance of a theory, or its simplicity, or its unity, not only functions as a heuristic factor in theory discovery and pursuit, but is often regarded as an indicator of truth. Scientists themselves, from Poincaré to Dirac have appealed to beauty when justifying their commitment to a theory. However, she asks, what is the connection here? On the one hand, it might be suggested that beautiful theories correctly capture facts about the world, so their aesthetic qualities reflect the beauty in the world. But this, of course, runs up against objections that it assumes that the world is beautiful, in whatever sense, and modern physics, as embodied in the Standard Model of elementary particle physics might suggest otherwise.

On the other hand, it could be argued that we should have confidence in a beautiful theory simply because, inductively, beautiful theories have had a good track record of empirical success. Here she draws on McAllister's use of the 'exposure effect' from psychology: scientists learn from exposure to the aesthetic qualities of past successful theories what features to invoke in the pursuit and evaluation of current theories. We can then induce that future theories possessing these qualities will be successful. Furthermore, the language in which such features are described should be taken literally, as discourse about the aesthetic qualities of the theories concerned, rather than a 'stand in' for non-aesthetic features.

However, Ivanova argues, this latter account cannot explain why certain qualities, such as simplicity and unity, persist throughout the history of science, while

others fade from the scene, despite being associated with empirically successful theories. More significantly, she regards this sort of argument as unduly 'optimistic' and points out that as the realism debate illustrates, the history of science can be used to give a very different conclusion. There are, after all, beautiful theories that have failed and 'ugly' ones – such as quantum mechanics perhaps – that are hugely successful.

However, she suggests, if we shift our epistemic aim from truth to understanding, the regulative role played by these qualities can be recognised and appropriately accommodated within our philosophy of science. Appealing to non-factive accounts of understanding, such as Elgin's or de Regt's, that treat it as a skill or ability, then opens up epistemic space for aesthetic qualities to play a role. The elegance or unity of a theory then reflects, not certain features of the world, but our choice to construct it along these lines and that is because we are then better able to manipulate and work with it. Taking these qualities as conditions of our cognitive make-up then explains why certain of them persist even when our best theories fail to exhibit them – in such cases the qualities are shifted to potential future theories that are sought after. Thus, she concludes, the significance of such aesthetic qualities in scientists' decision-making has to do with the way we think about the world and is independent of the question whether such qualities can lead us to expect that the theories we regard as beautiful are also likely to be successful.

Margherita Arcangeli and Jérome Dokic broaden the discussion by focusing on the 'sublime' in their paper 'A Plea for the Sublime in Science'. The sublime is often taken to contrast with beauty, not least because the former can be disturbing as well as enlightening. They begin by considering how experiences of beauty and the sublime are contrastive in this way, with the latter manifesting an overwhelming and,

often, negative aspect not present in the former. Beauty experiences tend to be positive and pleasurable, involving reward and satisfaction. Sublimity experiences, on the other hand, elicit a sense of vastness and grandeur that can be unsettling, at the very least. Both, however, can be considered aesthetic experiences, albeit corresponding to different cognitive patterns. And both play a role in science, although that played by the sublime has tended to be overlooked. On the one hand, the sublime can be an object of empirical investigation itself but on the other, it can also be a guide in scientific practice.

Thus, as Arcangeli and Dokic remark, scientists themselves use words and phrases such as 'mysterious', 'feeling of awe', 'frightening', that are evocative of sublimity experiences in both their positive and negative aspects. As they go on to describe, recent work by psychologists demonstrates that such experiences can themselves be the subject of scientific enquiry. Indeed, certain neurological findings indicate that experiences of the sublime activate different areas of the brain than do beauty experiences and also reflect the sense of a loss of self that are inherent in the former.

Furthermore, just as aesthetic qualities such as beauty can play an important role in scientific practice, so can the sublime. Indeed, a focus on the latter reveals significant features of such practice that might otherwise be overlooked. Consider, again, the relationship between truth and beauty. Whether this relationship can be ontologically grounded or not, it has been claimed that judgments about both share a common characteristic by virtue of being made through people attending to the fluency of their own information processing. Thus certain shapes are judged to be more beautiful than others because the relevant features can be processed more easily. Likewise, sentences that are easier to be processed, tend to be judged to be true.

Interiorising the associated heuristic relating beauty and truth underpins the mechanism that links the fluency based approach with the claim that such judgments play a role in scientific practice.

Significantly, this overall approach can then be extended along two avenues: first, to cover judgments of understanding and secondly, to include experiences of the sublime. Here Arcangeli and Dokic draw on a distinction between perceptual and conceptual fluency and argue that just as certain paintings, say, may be regarded as visually 'disfluent' but conceptually fluent, so experiences of the sublime in science may involve a similar balance of fluency and disfluency. Thus they suggest that judgements of sublimity may draw the attention of scientists to highly challenging phenomena and domains of enquiry and that these judgements may then contribute to the evaluation of a theory as innovative or ground breaking.

Finally, they insist, the objects of sublimity experiences are more relational than those of beauty experiences and this renders the former apt to ground deep judgements of understanding, with regard to the limits of human cognition. They may be characterised as 'limit-experiences' in the sense that they involve the feeling that the theory under consideration has been pushed towards the limits of what we may cognitively encompass as human beings. Sublimity experiences, then, may manifest at the deepest or most foundational levels of scientific practices, when we contemplate theories like quantum mechanics and General Relativity and as such, they are deserving of more comprehensive philosophical treatment.

Meynell, Ivanova and Arcangeli and Dokic primarily focus on theories as the bearers of the relevant aesthetic qualities. However, other products of science can also possess them. Alexander Bird looks at explanations in his 'How Can Loveliness be a Guide to Truth? Inference to the Best Explanation and Exemplars'. He begins by

noting that scientists frequently invoke 'Inference to the Best Explanation' in order to assess the plausibility of their theories. Lipton famously claimed that in this process explanations are ranked according to their 'loveliness' with the top ranked explanation chosen as 'the best'. Bird then asks, what are the lovely making features of an explanatory theory? And how do scientists come to see and respond to these features in a theory? An immediate issue in canvassing answers to these questions has to do with the objection that loveliness is subjective. In that case, it cannot be held to correlate with the truth. In part, as Bird notes, this has to do with the ineffable nature of loveliness – we are better at recognising it than we are at articulating what it is. Furthermore, there is considerable variation across different disciplines about what counts as lovely in an explanation. These are concerns that may also be applied to aesthetic features in general; so, for example, we may feel that Mozart's oboe quartet is beautiful without being able to articulate in terms of what properties it is beautiful. How might we assuage these worries?

Bird's response is to appeal to the idea that a community's standards of explanatory goodness are acquired in the process of scientific training and learning which uses certain *exemplars* (and here we might recall Elgin's work on their role). As he says, this notion of a scientific exemplar originates with Kuhn who emphasised the exemplary nature of certain solutions to scientific puzzles that then drive the processes of scientific cognition. It is the perceived similarity with the relevant exemplars that determines theory choice in science. Furthermore, scientists learn how to tackle the problems they are faced with through repeated exposure to and practice with these exemplars.

However, Bird argues, we can take this overall framework further and place it in a naturalistic and realist context in which we can account for our ability to latch

onto the truth in virtue of possessing certain reliable modes of thinking. Crucially, it is through exposure to exemplars that scientists acquire their standards of explanatory goodness, that is of 'loveliness'. As Bird notes, this really goes all the way back to Aristotle and the idea that we acquire our virtues not through learning certain rules but through a process of training and being exposed to examples of virtuous behaviour. Of course, it is due to the nature of that process that the judgments reached are not wholly a matter of rational, conscious deliberation. As a result the scientist in making such a judgment may not be able to fully articulate the reasons for doing so. And the factors involved will be dependent on the exemplars that the scientist was exposed to in their training.

Here we can see how the above worries might be dealt with. Indeed the ineffability of scientists' judgments about the loveliness of an explanation is entirely to be expected if the process of learning occurs through training with exemplars rather than the acquisition of explicit rules. And likewise, different scientific domains will invoke different exemplars and hence what we have across science are multiple sets of criteria of explanatory goodness. Indeed, we might even see a shift in such criteria within a given domain across time.

Nevertheless, as Bird goes on to note, this approach does not guarantee that the relevant exemplars will establish truth-conducive standards. The emphasis on certain analogies in medieval science is illustrative of that. To use a more recent example, the replication crisis in social psychology suggests that its exemplars are also not truth-conducive. Having said that, if the exemplars underpinning certain criteria are themselves true, then, Bird argues, those criteria can be conducive of the truth. Given all this, if success does indeed correlate with the truth and in discerning the explanatory features of exemplars scientists are, in fact, discerning properties that

play some role in the success of theories, then we may conclude that Inference to the Best Explanation is reliable. More generally, Bird argues that this exemplar-based approach exhibits a number of advantages over McAllistair's so-called 'aesthetic induction', mentioned above, according to which scientists make aesthetic judgments about theories that play a role in theory acceptance. In particular, Bird claims, the latter assumes that such judgments can be distinguished from those made on the basis of empirical criteria, whereas he is sceptical of this and insists that the exemplar based approach makes no such distinction. Given the central role of explanation in the assessment of theories, he maintains, we cannot assess a theory on empirical grounds independently of assessing it in terms of its explanatory goodness.

As he says in the conclusion, this role of exemplars can also be identified in the world of art where certain instances of 'great art' are held up as embodying the aesthetic qualities of beauty, sublimity and so forth, thereby setting the standard by which other works can be taken to possess these qualities. As in art so in science, where certain theories, historical episodes, problem solutions etc. are held up as exemplary. The difference, of course, is that in the case of the latter, if we adopt a realist stance, we should also maintain that the exemplar base standards of explanatory loveliness yield a preference for theories that are more likely to be true,

In her contribution, 'The Literary Form of Scientific Thought Experiments' Alice Murphy extends this focus from theories and explanations to thought experiments that, as Elgin has also noted, play such a crucial role in the progress of science and which may also be described as 'beautiful' or 'elegant'. Thus she takes Galileo's 'falling bodies' thought experiment that spelled the end for the Aristotelian view of motion and which has been described as 'the most beautiful thought experiment ever devised' and asks what it is, precisely, that makes this example so

beautiful. One option is to appeal to certain non-aesthetic features in order to explain our use of aesthetic terms in such cases. In the case of a concrete experiment, we may refer to its optimal use of minimal material, for example, and we can extend this to thought experiments, where the relevant economy can be cashed out in terms of the particulars that we are prescribed to imagine. Here Murphy draws a useful contrast with thought experiments that are described in negative terms, as in the example of Szilard's version of Maxwell's Demon, described as 'the worst thought experiment ever'. This exhibits an apparent misuse of certain idealisations, leading to confusion, or, in the case of Darwin's whale analogy, 'needlessly strange' explanations. However, she goes on to insist that we can understand the aesthetic evaluation of thought experiments in a broader sense that illustrates their commonalities with works of literature. This then reveals their differences from both theories and concrete experiments.

As Murphy notes, works of fiction have themselves been described as extended thought experiments that may reveal fundamental insights about both the world and ourselves. Greene's *The Third Man*, for example, has been portrayed as a thought experiment on the tension that may arise between maintaining loyalty to a friend and loyalty to a cause. Scientific thought experiments may also be presented in a narrative form, such as Newton's famous bucket experiment, and Elgin has argued that we can identify a continuity between concrete experiments, thought experiments and literary works. All involve a certain degree of control of a scenario as well as the use of idealisation, with differences within each case regarding how far and what ways they diverge from reality.

Moving in the other direction, from literature to science, Murphy considers how the aesthetic choices scientists make in the design of thought experiments

contribute to their function in terms of communicating, convincing, or explaining a theory or phenomena to a scientific or a public community. Thus part of their value in the scientific context has to do with the features they share with literary works. However, it may be objected that there are clear disanalogies between the two. So, for example, Norton maintains that thought experiments are merely disguised arguments and hence their aesthetic qualities are dispensable. Similarly Egan argues that the purpose of a thought experiment is exhausted by its contribution to an argument. On the contrary, Murphy argues, although we may reconstruct thought experiments as arguments, in doing so we effectively lose sight of certain features that are crucial to the practice they are associated with. As Gendler has noted, the demonstrative force of the thought experiment is much diminished if we reconstruct it in the manner that Norton and Egan suggest. In the case of Galileo's falling bodies example, we lose the way in which tacit knowledge of how bodies fall block certain Aristotelian objections.

According to Murphy, it is through the introduction of the particulars and familiar objects, such as Galileo's towers and balls, that we engage with the thought experiment, and therefore come to understand what it and the relevant theorising is all about. Given that thought experiments depend upon our imaginative capacities, these features must obviously be carefully chosen.

Frigg and Nguyen have also pointed out that literary works and thought experiments differ in that interpretation is a much more flexible affair when it comes to the former as compared with the latter. Here Murphy appeals to the distinction between the description of a work, whether artistic or scientific and an interpretation of it. If we take account of this, the difference between artworks and scientific models, say, begins to evaporate, with many of the constraints on scientific models say, that have been attributed to interpretation falling under description, with similar

constraints applying to literary works. Relatedly, Murphy notes, thought experiments may have a greater range of interpretation than one might initially suspect and indeed, it is part of their scientific value that they may revised and their impact contested.

Finally, Murphy suggests that in comparing thought experiments and works of fiction, a certain degree of care needs to be taken when it comes to choosing the relevant comparators. Short stories and speculative fiction might be better choices than longer, realist works. Perhaps the most apposite examples are fables and parables, where the point is also to persuade or explain and a simplified scenario is presented, involving everyday or familiar objects and here Murphy notes the similarities with Cartwright's comparison between models and fables. Hence Murphy concludes, the differences between thought experiments and artworks don't account for the use of the former in scientific practice, and part of their value in this context includes the qualities that they share with the latter.

Both Arcangeli and Dokic and Murphy emphasise the transformative function of aesthetic features, whether to do with the sublime or beauty, and indicate how they contribute to revolutionary theory change. In his paper, 'Epistemic Radicals and The Vice of Arrogance as a Counterfeit to the Virtue of Assured Epistemic Ambition', Matthew Kieran also considers the innovative and revolutionary aspects of scientific practice and examines the features possess by the 'epistemic radicals' who effect such dramatic shifts. As he notes, such features are often associated with epistemic vices, such as arrogance and competitiveness. Consider the great mathematician John Nash, for example, perhaps most famously known for his work in game theory but who also made fundamental contributions to the study of partial differential equations and who was also renowned for his arrogance and self-confidence. As Kieran notes, studies show that many creative scientists exhibit such vices. However, this then generates a

tension, since epistemic vice is supposed to tend towards epistemic failure, and yet if it is the mark of the epistemic radical how can being such a radical be deemed to be an epistemic good?

Kieran dissolves the tension by arguing that arrogance, for example, can be seen as a 'counterfeit virtue', in the sense that it has an overlapping behavioural profile with assured epistemic ambition that does not fall prey to the epistemic error and misdirection that are associated with arrogance. Conceptualizing arrogance as an epistemic vice standing in a counterfeit relation to the true epistemic virtue of assured ambition in this way then explains why such epistemic radicals can be either heroes or villains.

Thus he begins by noting how arrogance may be bound up with the characteristics of an epistemic radical, by helping to generate ambition and drive, for example. Nevertheless, it can also generate reckless ambition that is manifested in carelessness over methods, taking short cuts and epistemic licence more generally, leading to projects failing. Here Kieran cites the example of Lysenko and, more recently, Stapel who faked his data to prove what he 'knew' to be true already.

The counterpart to this vice is the virtue of assured epistemic ambition, which involves not just the internalization by the scientist of certain aims as having significant value or being valuable for their own sake and the commitment to appropriately pursue such aims, but also an epistemically permissible high degree of self-trust in presuming she has a good enough chance of realizing them. Thus the Curies, for example, seem to have been driven by the aim of discovering knowledge for its own sake. Hopkins, on the other hand, dedicated his life to wiping out infectious tropical diseases in order to alleviate widespread suffering. However, as

Kieran emphasises, it is enough to have such lofty aims – one must have the right kind of commitment to them and go about achieving them in an appropriate manner.

This does not mean that the epistemically ambitious should not take risks; on the contrary, such people typically adopt new approaches in pursuit of their aims and have a justifiable trust in themselves in doing so. This in turn does not preclude self-questioning – indeed, according to Kieran what we often see is a virtuous cycle of self-development involving an ever-increasing 'upskilling' that places the scientist in a better position to realise great ambitions. As a result she will be well-situated to become an epistemic radical without succumbing to the tendency of the arrogant to error or misguided approaches.

Having said that, both those who possess the virtue of assured epistemic ambition and those who are arrogant may end up regarding only a comparatively select few people as their epistemic peers. They may both tend to dismiss the views of others, preferring to investigate the matter at hand for themselves. However, Kieran argues, those who are assuredly ambitious typically possess strengths that their arrogant counterparts do not have and are not susceptible to the failings of the latter. Examples include close-mindedness and a presumption to an entitlement of success that the ambitious can avoid through appropriate self-reflection.

Given all of this, Kieran concludes, we should regard such arrogance as a vice that is a counterfeit virtue to the true virtue of assured epistemic ambition. As he goes on to suggest, this may have practical implications, including the perpetration of epistemic injustice as in cases where people from disadvantaged groups are construed as arrogant when they manifest the epistemic profile of assured epistemic ambition precisely because that profile is in tension with the profile that is stereotypically assumed for members of that group. An obvious example here would be women in

mathematics and science (or, indeed, philosophy). Furthermore, although normatively we might want to encourage the possession of such a virtue it might be objected that we don't want scientists to be radicals all the time – as Kuhn famously pointed out, much of scientific work involves problem solving and what he called 'normal' science. One's response to this depends on how one regards virtues more generally. The 'global' virtue theorist may insist that such a virtue is partly constitutive of what it is to be a good scientist but that it doesn't need to be manifested all the time. Of course, there are numerous examples of scientists who do not have the ambition of the epistemic radical but still produce good scientific work. As Kieran notes, a 'situational' approach acknowledges that all we need for scientific progress is for some individuals or teams to possess this virtue and that the scientific community in general can present a mix of epistemic 'moderates' as well as radicals.

Like Murphy, French is concerned with the comparison between scientific theories and certain artworks, in his case specifically musical works. With regard to the ontological status of both it has been suggested they should be viewed as abstract entities sitting in some equally abstract space, such as Popper's infamous 'World Three'. The worry with such views is that they have difficulty accommodating the heuristic processes by which theories are discovered – at what point in such a process, for example, does a theory appear in this abstract space? Here he explores an alternative view, due to Collingwood, that takes both artworks – and not just musical works and novels, but also paintings – and also scientific theories to be 'imaginary things'. This obviously allows for the accommodation of creativity and the heuristic process by which both artworks and theories are brought into being. However, it equally obviously suffers from the problem of inter-subjective inaccessibility.

Collingwood's solution is radical: the audience of a piece of music do not actually hear the artist's creation, rather they reconstruct it in their own imaginations. This then raises the further problem of whether that reconstruction could be said to be the same as the artist's work and here the issue of what count as the identity conditions for artworks looms large. French canvases Wollheim's type-token account as well as Zemach's relative identity approach and concludes that neither is up to the job. As an alternative he suggests that we give up on establishing such conditions and accept that what is in each of the audience members' minds is different from what is in the artist's, and each others, but that there is sufficient commonality for critical engagement to occur.

Interestingly, Collingwood himself compares a musical performance to a scientific presentation and argues likewise that the scientist's thesis is reconstructed in the minds of the audience members. Here too issues of identity arise: was the theory of Special Relativity that Einstein had in mind in his annus mirabilus of 1905 the same theory as the one that Planck subsequently presented? And were either the same as Lorentz's theory or the 'version' presented by Minkowski? At the very least it remains unclear how we are to answer these questions or the further one as to whether the reconstruction that we engage in when we read Einstein's paper correspond to the theory *he* had in mind.

Again, French suggests, we should abandon the search for such identity conditions on theories and the associated attempts to place them in some ontological pigeonhole. Instead we should follow Ridley who urges philosophers of music to shift their focus to the practices of performances. Consideration of the corresponding scientific 'performances', in the form of lectures and conference presentations, for

example, has been generally absent in the philosophy of science but historians have long noted the performative aspect of science.

If we then accept that there are no theories for which identity conditions need to be provided, we can take such performances and scientific practices in general as providing the truth-makers for claims that are putatively 'about' such theories. Thus, French argues, the statement that 'Special Relativity is empirically adequate' is made true by the complex set of practices involved in the testing of certain claims, such as, famously, those involving length contraction and time dilation. This can then be extended to claims such as 'Special Relativity is an elegant theory', which is made true by the relevant practices – so, for example, if elegance is understood as cashed out in terms of some combination of parsimony and power, then the statement is made true by the relevant practices, involving, for example, the ease of deduction of certain statements from the axioms or fundamental claims of the theory, the way in which a wide variety of claims (both theoretical and empirical) can be obtained from these axioms and so on.

French concludes by suggesting that this shift to practices may offer a third way between those who dismiss such aesthetic qualities as merely subjective and those who accord them a degree of objectivity: they are objective not in the sense of corresponding to features of the world but in that of being embodied in the relevant practices that scientists engage in, and here we can see connections with Ivanova's work, for example.

Although this is a diverse array of contributions, we hope to have indicated a number of core themes: the relationship between aesthetic qualities, such as beauty and sublimity, and their contribution to scientific aims such as understanding and truth, the possession of such qualities by different features in scientific practice, from

theories and explanations to thought experiments, and the attitude toward such qualities by scientists themselves. And more generally, these themes entwine around the central relationship between the philosophy of art and the philosophy of science, across which various devices and approaches can be carried, from one side to the other, to the benefit of both.

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