

# Aesthetics in Science: A Kantian Proposal

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Can aesthetic judgements legitimately be linked to the success of scientific theories? I suggest that a satisfactory answer to this question should account for the persistent attraction that aesthetic considerations seem to have for scientists, while also explaining the apparent instability of the link between the beauty of a theory and its truth. I argue that two widespread tendencies in the literature, Pythagorean and subjectivist approaches, have difficulties meeting this twofold challenge. I propose a Kantian conception of aesthetic judgements as second-order considerations, related to our own intellectual capacities for making sense of the world, and argue that it fares better.

## I

*Introduction.* Many of the greatest natural philosophers and scientists have attached central importance not only to the empirical success but also to the aesthetic merit of their proofs, explanations and theories. Key figures in the history of science, ranging from Johannes Kepler to Henri Poincare, Albert Einstein, Hermann Weyl, Werner Heisenberg and Paul Dirac in physics, and from Charles Darwin to James Watson, Francis Crick and Rosalind Franklin in biology, were explicitly concerned with beauty and elegance. Poincare, for example, regarded the beauty of nature as a motivation for scientific enquiry, claiming that the ‘scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it; and he takes pleasure in it because it is beautiful’ (Poincare 1908, p. 22). Many went further, taking beauty to be not only a motivation for the scientist, but an indication of the truth of theories. As Heisenberg put it, ‘If nature leads us to mathematical forms of great simplicity and beauty ... we cannot help thinking that they are “true”, that they reveal a genuine feature of nature’ (Heisenberg 1971, p. 68). And, even more pointedly, Einstein argued that the only physical theories we are willing to accept are the beautiful ones (reported in Wigner 1960, p. 5), while Dirac claimed that ‘[a] theory with mathematical beauty is more likely to be correct than an ugly one that fits some experimental data’ (Dirac 1970, p. 29). Moreover, as Watson remembered, Franklin found the double helix model of the structure of DNA simply ‘too pretty not to be true’ (Watson 1968, p. 164).

While this focus on aesthetic considerations may be widespread among scientists, it raises difficult questions. Why should considerations as possibly subjective and most probably contestable as aesthetic judgements play a role in science with its *prima facie* aim of securing objective knowledge? What bearing would the beauty of a scientific claim have on its truth? Can aesthetic criteria legitimately be linked to the truth of theories?<sup>1</sup>

In the literature, treatments of the relation between the beauty and truth of scientific theories display two widespread tendencies. Pythagorean approaches, on the one side, affirm an intrinsic connection between beauty and truth, while subjectivist approaches, on the other, see beauty as having, at best, a purely contingent link to the truth of scientific theories. As I shall argue in the next section, however, both views have their problems. While the first fails to account for the apparent instability of the link between beauty and truth attested to by the historical evidence, the second is forced to reject outright a large part of how scientists themselves characterize their research activity when they claim to rely on aesthetic considerations.

My aim in this paper is to propose an alternative conception of beauty in science that avoids the difficulties on both sides. That is, I seek an account that credits scientists' aesthetic considerations without relying on an alleged metaphysical connection between beauty and truth. Taking inspiration from Kant's aesthetic theory, I suggest that we can understand the aesthetic appreciation of scientific claims as linked to the character of our own intellectual activities involved in doing and understanding science. Moreover, I propose that it is because of this relation of aesthetic judgements with the conditions of understanding that scientists have a reason to take considerations of beauty into account. I argue that through their link to understanding, aesthetic judgements are legitimately appealing to scientists, even though such judgements are not necessarily an indication of truth.

My proposal is motivated by the observation that discussions of beauty in science usually focus on the link between beauty and truth without clarifying the conception of aesthetics that informs such discussion.<sup>2</sup> By contrast, I believe that beginning with an analysis of the notion of aesthetics is crucial for shedding light on the role that considerations of beauty can play in the study of nature. By focusing on the question of how to construe aesthetic judgements in science, I thus seek to shed light on the relation of such judgements to the aims of science.

My argument will take the following three steps. I begin, in §11, by saying a few words about the Pythagorean and subjectivist views and about some of the problems they raise. I then spell

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<sup>1</sup> For simplicity, I shall focus on the beauty of theories. I believe that my conclusions can be shown to extend beyond theories, however, including aesthetic considerations about hypotheses, explanations, proofs and experiments.

<sup>2</sup> There are a few exceptions. Kivy (1991), for example, discusses the problems of aesthetic formalism for dealing with the question of beauty in science. McAllister (1996, pp. 29ff.) explicitly aligns himself with a projectivist account of aesthetic value.

out my alternative proposal in two stages. In §III, I develop a Kantian conception of aesthetic judgements in science as second-order judgements that relate only indirectly to the object judged and directly to our own reflection on the object. According to my proposal, we appreciate a theory aesthetically when, in reflecting on the theory, we become aware of the harmony of our own intellectual capacities and their suitability for making sense of the world. Moreover, in §IV I argue that if we take this conception as our starting point, we can provide an account of the relation of aesthetics to the aims of science which promises to overcome the problems raised by the Pythagorean and subjectivist positions. More specifically, aesthetic considerations may legitimately appeal to scientists not because the phenomena themselves really are simple or elegant but because, in searching for beauty, scientists aim for theories that provide understanding. Although aiming for understanding of the phenomena does not by itself guarantee a path to truth, providing understanding is a necessary requirement for any successful theory. Scientists may therefore have a reason to take considerations of beauty into account.

My argument for a Kantian conception of aesthetics in science will thus be indirect. Instead of attempting to justify the proposed second-order conception of aesthetic judgements head-on, my aim is to present it as a viable alternative that, if adopted, promises to solve the problems facing the Pythagorean and subjectivist accounts. By thus putting into focus the nature of aesthetic judgements, I offer a proposal for how to construe the role of such judgements in scientific inquiry. Instead of laying down determinate criteria for distinguishing aesthetic considerations which lead to true theories from those which do not, I suggest that concern for the connection of beauty and truth should be replaced by an investigation into the relationship between beauty and understanding, on the one hand, and understanding and truth, on the other. While this paper will be largely focused on the first link, between beauty and understanding, I aim to map out a robust framework for a more comprehensive investigation into the nature and function of aesthetics in science.

## II

*Two Tendencies: Pythagoreanism and Subjectivism.* Many scientists who explicitly engage with the question of beauty in their work seem to harbour what I shall call ‘Pythagorean’ tendencies.<sup>3</sup> The core idea here is that there exists a profound and intrinsic connection between the beautiful, on the one hand, and truth on the other. More specifically, this view can be

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<sup>3</sup> Chandrasekhar (1987, pp. 59ff.) gives an account of the prevalence of this Pythagorean conception amongst physical scientists of the nineteenth and twentieth centuries. A recent adherent to this view is Zee (1999), in his more popular ‘search for beauty in modern physics’ (see in particular pp. 8ff.). Bangu (2007) helpfully distinguishes different strands of the Pythagorean conception.

understood as a combination of two claims, the first about the nature of aesthetic judgements, the second about the link of such judgements to truth.

First, according to the Pythagorean conception, aesthetic considerations do not consist in any subjective, idiosyncratic response but in the intellectual grasp of certain properties such as those of simplicity, symmetry, or unity among diversity. Aesthetic judgements in science, according to this conception, are judgements about the objective features of theories. Poincare gives a clear statement of this view when he claims that the kind of beauty which is relevant to science is not ‘that beauty which strikes the senses’; it is a ‘special’ kind of beauty, a ‘beauty which comes from the harmonious order of its [i.e. the science’s] parts, and which a pure intelligence can grasp’ (Poincare 1908, p. 22). Beauty, Poincare here claims, is a property that has to do with harmonious order and, more importantly, it is a property to which we have intellectual access.<sup>4</sup>

Second, it is then usually assumed that theories which have aesthetic properties are more likely to be true than those which lack such properties because nature itself has corresponding aesthetic qualities. According to the Pythagorean account, a theory’s aesthetic features are thus intrinsically tied to its truth because they track real properties in the phenomena. A simple theory is more likely to be true than one which adds extra complexity, for instance, because the natural world is governed by simple laws. Thus, if the beauty of Darwin’s theory of evolution consists in its simplicity, then its simplicity would, in turn, give insight into the simplicity of the principle underlying the evolution of species. As the physicist Subrahmanyan Chandrasekhar puts it, ‘what the human mind perceives as beautiful finds its realization in nature’ (Chandrasekhar 1987, p. 28).

While this approach can account for many typical claims about beauty to be encountered among scientists,<sup>5</sup> it also faces a number of serious problems. Here I shall mention only one of the most pressing, concerning the historical evidence which appears to be strikingly at odds with both parts of the Pythagorean position.<sup>6</sup> More specifically, developments in the history of science seem to speak against the objective status of aesthetic judgements as well as the proclaimed intrinsic link between beauty and truth. Thus, in the past, scientists have not always agreed on which theories should or should not be regarded as beautiful, and aesthetic judgements have varied over time and with social and cultural context. Some theories were rejected as awkward and even ugly at first but considered natural and elegant from later perspectives. In the seventeenth century, for example, many rejected Kepler’s elliptic model of

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<sup>4</sup> See also Dirac’s statement according to which aesthetic judgements ‘depend on one’s culture and upbringing for certain kinds of beauty, pictures, literature, poetry, and so on. ... But mathematical beauty ... is of a completely different kind and transcends all personal factors’ (quoted in Dyson 1987, p. 102).

<sup>5</sup> See, in particular, the claims quoted at the beginning of the current paper.

<sup>6</sup> For a discussion of further problems, see McAllister (1996, pp. 90ff.).

planetary motion on aesthetic grounds. But while Kepler's ellipses may have jarred with the aesthetic ideals of harmony and simplicity, and with the associated commitment of astronomy to uniform circular motion, they fitted nicely with Kepler's preferred Mannerist conception of aesthetics that made room for more playful forms.<sup>7</sup> Similarly, with the rise of Romanticism in the nineteenth century, new aesthetic ideals such as that of organic unity became prominent in the sciences.<sup>8</sup> If, as these examples suggest, aesthetic appreciation is open to variation between different scientists and historical periods, then this raises questions about the proclaimed objectivity of aesthetic judgements in science.

Moreover, as the history of science also attests, aesthetics has not always been a reliable guide to truth. Theories that were considered preferable on aesthetic grounds have in fact failed, while theories that were rejected for aesthetic reasons by some have been corroborated over time. Thus, Newton's laws of motion and gravitation were widely considered as offering an elegant explanation of a vast body of astronomical observations.<sup>9</sup> But while they provided fundamental steps in the development of physical science, they were precisely that, steps to be advanced upon and superseded by modern physics. Moreover, many physicists have found quantum theory, with its lack of visualization and its apparent implications of indeterminism, aesthetically displeasing.<sup>10</sup> And yet, quantum physics is alive and well today. The historical evidence thus also raises serious doubts about the proclaimed intrinsic connection between the beauty of a theory and its truth.

Should we conclude, then, that scientists' judgements of beauty have purely subjective validity? And should we regard the aesthetic appreciation of a theory as having at best a contingent connection to its truth? As I have suggested, the tendency to give positive answers to these questions competes with the Pythagorean approach in the literature. We can again distinguish between two parts of the position. According to the subjectivist, aesthetic considerations, first, have no objective validity, and second, lack any intrinsic or necessary connection with the truth of scientific claims. Chandrasekhar expresses the first element of this view when he claims that to 'examine a physical theory and to state its aesthetic appeal is beset with difficulties. Like all discussions relating to beauty, it is subject to the tastes and temperaments of the individuals' (Chandrasekhar 1987, p. 153). James McAllister spells out the second claim, moreover, when he concludes that 'scientists' canons for theory evaluation will be

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<sup>7</sup>Jardine (1998) gives an account of the Mannerist ideals which informed Kepler's cosmology.

<sup>8</sup>Holmes (2009, p. xv) argues that 'Romantic science' was the result of what he describes as 'the second scientific revolution, which swept through Britain at the end of the eighteenth century'.

<sup>9</sup>For an account of the beauty of Newton's system, see Heisenberg (1974, pp. 6f.).

<sup>10</sup>On Dirac's rejection of Schwinger and Feynman's theory of quantum electrodynamics because of its ugliness, see Dyson (1987, p. 103). Hoffman and Dukas (1972, p. 193) describe Einstein's rejection of indeterminism as a matter of 'faith and feeling and intuition'.

prey to [aesthetic] fashions' (McAllister 1996, p. 85), where such fashions have no necessary connection to truth.<sup>11</sup>

The subjectivist position has an important advantage over the Pythagorean conception, since it can explain the apparent instability of the connection between beauty and truth in the history of science. The difficulty is, however, that it cannot account for the significance that scientists attribute to aesthetic judgements. Scientists may think that a beautiful theory points towards its truth, but, according to the subjectivist proposal, they would be judging incorrectly. Scientists may think that beauty has a value in science over and above our idiosyncratic interests, but again they would be mistaken. While I do not want to rule out at the outset that this deflationary proposal may in the end turn out to be correct, I believe that it is a little too quick in dismissing the attraction of aesthetic considerations in science. Can we do better in explaining the consistent appeal that aesthetic considerations seem to exert on scientists?

I suggest that the difficulties raised by these two opposed tendencies should inform the desiderata that an account of aesthetics in science ought to satisfy. In the following two sections, I therefore propose an approach that aims to account for both the difficulty associated with the attempt to establish an intrinsic connection between beauty and truth, and the apparent attraction that aesthetic considerations nevertheless have for many scientists. I thus aim to develop a conception of beauty in science that can account for the apparently unstable link of beauty and truth, while also going some way towards showing that this link is not altogether arbitrary.

### III

*Beauty and Understanding.* I would like to propose a different way of thinking about aesthetic judgements in science that construes such judgements as neither consisting in objective claims about the particular properties of scientific theories (as the Pythagorean proposes) nor relying on purely subjective responses to such properties (as the subjectivist holds). Instead, I suggest that we understand the aesthetic appraisal of a theory as a response to the experienced harmony of our intellectual capacities and their suitability for making sense of the world. My proposal is inspired by aspects of Kant's conception of aesthetics. I shall therefore say a few words about the key elements of Kant's approach that I want to draw on, before examining how they may shed light on the particular case of aesthetics in science.

Judgements of beauty, according to Kant, are essentially dependent on the subject's active engagement with the object. They do not make any determinate claim about a property in the

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<sup>11</sup> On McAllister's proposal see note 18 below.

object but are the result of the subject's way of reflecting on the object. It is this mode of reflection, on Kant's account, that we experience as aesthetically pleasing. Kant thus essentially contrasts judgements of beauty with determinate claims about the objective features of the world. Moreover, he also distinguishes aesthetic judgements from ordinary emotional responses. Rather than consisting in purely subjective feelings, which may vary between individuals depending on their particular interests and preferences, aesthetic responses demand the agreement of others. Even though they are not anchored in any objective property by reference to which they could be justified, they make a claim to intersubjective validity.

Kant develops this twofold characterization of judgements of beauty in the *Critique of Judgement* by reference to what he calls the 'free play' of our mental faculties, that is, the spontaneous interaction of understanding and imagination (Kant 2000, p. 103; V 218).<sup>12</sup> In aesthetic experiences, Kant argues, we play around in imagination with what we perceive through the senses in a way that is suitable for (or 'in harmony' with) conceptual understanding, without, however, settling on any determinate conception of the object (Kant 2000, p. 103; V 218). By combining and recombining various features of our sensory impressions of the perceived object in imagination, we present it to ourselves as something that makes sense to us without representing it as an object of any particular kind. It is our awareness of the free and harmonious interaction of our intellectual activities involved in reflectively engaging with the object in this way, an awareness that is not distracted by any conceptual representation of the object, that triggers the feeling of aesthetic pleasure. As Kant puts it, 'we are conscious' of the activity of our mental faculties 'with the sensation of satisfaction' (Kant 2000, p. 90; V 204). Aesthetic pleasure, therefore, does not result when any of our particular preferences are met, or when we recognize that the object has such and such properties, but from our being aware, in reflecting on the object, of the free play of intellectual faculties. Furthermore, since we all have the same intellectual capacities, Kant claims that aesthetic judgements essentially incorporate a 'claim to validity for everyone' (Kant 2000, p. 97; V 212).

While one may take issue with the details of Kant's story about the free play of the faculties, I believe that the account offers two important insights that may shed light on the particular problem of aesthetics in science. First, on Kant's conception, an aesthetic judgement is a second-order response. It is not a first-order judgement about any aesthetic property in the object. This construal of judgements of beauty accounts for the fact that, even if we knew all the properties of an object, it would nevertheless be an open question whether or not the object is beautiful. Whether or not the object can or will be judged beautiful furthermore depends on the viewer,

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<sup>12</sup> For detailed treatments of Kant's notion of 'free play', see, for example, Guyer (1997, pp. 60ff.) and Zuckert (2007, pp. 279ff.).

and her reflection on the object. Second, while an aesthetic judgement is only indirectly concerned with the object of experience, it is directly related to our intellectual activities involved in reflecting on the object. This further aspect of Kant's conception accounts for the thought that, even though we cannot definitively prove the adequacy of an aesthetic judgement by pointing to particular features of the object, we do not regard the judgement as entirely contingent upon the individual's subjective point of view. Rather, we regard such judgements as being similar to objective judgements in virtue of containing a claim to universality. It is this feature which distinguishes aesthetic judgements from claims about ordinary emotions, where we do not want to insist that others come to feel about things in the way we do. And it is this feature, moreover, which accounts for the phenomenological difference between aesthetic experiences and other emotional reactions. For only the former but not the latter appear to engage us intellectually.

Taking these two Kantian claims on board, I propose to construe the ascription of beauty to a scientific theory as similarly concerned with a second-order response to our intellectual engagement with the theory. More specifically, I suggest that it is a response to our awareness of the suitability of our intellectual capacities for making sense of the world around us. In regarding a theory as beautiful, we are thus not directly responding to what the theory says (e.g. that it derives the law  $F = ma$ ), or to how the theory says it (e.g. that it derives the law through a series of simple steps). Rather, in aesthetic judgements, we express our delight in the experienced harmony between the power of our intellect and the world, an experience of harmony of which we become aware through our engaging with the theory.<sup>13</sup>

Aesthetic judgements in science are thus essentially self-reflective on my proposal. Even though such judgements may appear to be about the property of theories, they express an

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<sup>13</sup> It may be objected that, strictly speaking, feelings of the kind described are only improperly called 'aesthetic' on Kant's account. Kant explicitly construes the free play of imagination and understanding that grounds aesthetic judgements as non-conceptual. But scientific understanding is essentially conceptual. A number of commentators have therefore concluded that science is not the kind of thing that can be regarded aesthetically on Kant's account, for example, Rueger (1997), as well as Koriako (1999, pp. i54ff.) and Wenzel (2001), who discuss the particular case of mathematics. See also Giordanetti's treatment (1995) of the relationship of genius, artist and scientist in Kant. I cannot discuss this problem of Kant scholarship here, and do not intend to defend any exegetical claims in the paragraph above. I believe, however, that the objection is ultimately misguided. First, Kant (2000, pp. 238f.; V 366) explicitly recognizes the possibility of beauty in mathematics. On Kant's account, mathematical proofs can elicit in us a sense of aesthetic appreciation because they make us aware of the creative intellectual activities involved in the process of mathematical reasoning. The pleasure we feel in mathematics is thus only indirectly a response to a particular demonstration, and directly linked to the spontaneous activity of our conceptual and imaginative capacities. For a detailed discussion of this, see Breitenbach (forthcoming). Moreover, even though Kant does not explicitly leave room for beauty in the natural sciences, I believe that more can be said to demonstrate its possibility on his account. For even if scientific theories are spelled out and understood conceptually, their discovery and our ability to apply them to natural phenomena require intellectual processes that ultimately include spontaneous and non-conceptual activities. An adequate defence of this claim will have to be deferred to another occasion.



appreciation that is ultimately based on the reflection on our own intellectual activities. This reflection may come in different forms. It may be reflection on the intellectual capacities involved in first constructing a theory and gaining understanding of the phenomena that the theory purports to explain. This, I think, is what Heisenberg refers to when he describes his aesthetic appreciation of quantum mechanics as a feeling of excitement about the insight gained through the calculations that led him to the formulation of his theory (Heisenberg 1971, pp. 60 f.). Alternatively, the reflection may be one directed at our intellectual engagement with an existing theory by means of which we gain understanding of the world. Thus, Darwin's theory of evolution may strike us as beautiful when, through it, we become aware that we can understand a host of apparently messy phenomena by means of a simple idea. In both cases of the construction of new theories and the understanding of extant ones, I thus suggest, we can understand the aesthetic judgement as ultimately a response to the experienced harmony of our own intellectual capacities involved in gaining understanding of the natural world by means of the theory.

The proposed conception can, I believe, account for the fact that features of a theory including, for example, its simplicity, capacity to unify a variety of phenomena, explanatory power, and fruitfulness have typically been regarded as aesthetic. For, by theories with these properties, we can make phenomena understandable to us, and thus become aware of the power of our intellect for making sense of the world. While a more comprehensive account will have to look at different aesthetic criteria on a case by case basis, it seems *prima facie* plausible to suggest that the listed features fit the proposed account. Thus, a simple theory makes understanding easier; a unified theory helps us to understand a variety of phenomena in a way that draws out the relations between those phenomena; a theory with strong explanatory power makes understanding of a large set of phenomena possible by subsuming them under a smaller number of general principles; and a fruitful theory enables understanding in other areas of enquiry. Furthermore, a theory may strike us more or less obviously as beautiful, depending on whether understanding is achieved more or less easily by means of the theory. And whether understanding is achieved more or less easily may, in turn, depend on whether the theory instantiates such properties as simplicity or unity.

Moreover, while the proposed conception can account for the Classical aesthetic ideals that have received much attention in the physical and mathematical sciences, it also leaves room for other aesthetic criteria. It can, for example, account for Kepler's Mannerist conception according to which theories that explain how the appearance of multiplicity and chaos can be produced by a unified ordering principle are regarded as aesthetically pleasing. Theories that realize such Mannerist ideals can be beautiful, on the proposed account, because they provide

understanding of the appearance of chaos by reference to a simple principle and can occasion the second-order awareness of harmony which grounds aesthetic experience. The advantage of my Kantian proposal in accounting for aesthetic considerations in this way is thus that it promises to explain the apparent diversity of aesthetic criteria in different sciences, cultural settings and historical periods as grounded in a common constant, that is, the felt harmony of our intellectual faculties and their suitability for making sense of the world. For it is not simply such aesthetic properties as simplicity or unity that determine whether a theory may be judged beautiful. Rather, we ascribe beauty to theories with such qualities in so far as these theories make us aware of the suitability of our own intellectual capacities for understanding the world. What are commonly regarded as aesthetic criteria are thus properties of theories that are only indirectly the source of an aesthetic response, where such a response directly relates to the experienced power of our intellect for making sense of natural phenomena.

#### IV

*Beauty, Understanding and Truth.* How, then, does this conception of aesthetics shed light on our original question regarding the relation between beauty and truth? I suggest that even though aesthetic judgements do not infallibly indicate the truth of theories, they may offer a legitimate guide for scientists. More specifically, I propose that because of the link to our capacities of understanding, following beauty can provide a heuristic means for choosing between theories, even though there is no intrinsic connection between beauty and truth. I believe, moreover, that this proposal promises to fulfil the desiderata I have laid down for a satisfactory answer to the question about the role of beauty in science. By contrast with the Pythagorean, it can account for the instability of the connection between the beauty of a theory and its success. By contrast with the subjectivist, it can do so without conceiving of this connection as altogether arbitrary or contingent on subjective considerations. The proposed conception can thus ascribe to aesthetic considerations a legitimate and non-arbitrary place in science without recourse to any metaphysical connection between beauty and truth. Let me develop these claims in more detail.

The apparently unstable relation between aesthetic judgements and the success of theories in the history of science is compatible with the proposed conception in so far as this conception allows for various ways in which beauty and understanding may come apart. We may thus gain understanding of the world by means of a theory without finding it beautiful. A case such as this underwrites the claim that the beauty of a theory is not simply determined by its helping us achieve understanding. It is triggered by a further reflection resulting in our awareness of the fit between our capacities of understanding and the world around us. Even if we gain understanding in a particular case, it is therefore a further question whether or not we become

reflectively aware of this harmony. Whether or not such awareness is achieved may be affected by the particular circumstances of the subject; she may be too preoccupied with understanding the theory to appreciate it aesthetically, for example. Furthermore, the subject's awareness may also be influenced by aspects of the theory itself; the theory may be so complicated that understanding is gained only with difficulty, for instance. In cases such as these, it is possible, and indeed unsurprising, if theories are not appreciated aesthetically even though they provide understanding.

In other cases, theories may please us aesthetically yet turn out to be mistaken. Thus, moreover, we may consider a theory beautiful when we believe it helps us understand the world, regardless of whether that belief is correct. If we are mistaken about our belief that we have understood something, aesthetic appreciation may fail to track genuine understanding. In trivial cases, where we have simply overlooked an important aspect of the phenomena to be explained, or are confused about an element of the theory, such mistakes can be corrected by our peers. In less trivial cases, theories may be considered beautiful by a whole generation of scientists even if they later turn out to be false. Even in such cases it nevertheless seems plausible to say that the theories were considered beautiful given that, within their context and against the relevant background knowledge, they appeared to provide understanding of the phenomena. They seemed to increase understanding, for instance, by subsuming unknown as well as known phenomena under the same general principles. Moreover, we may be able to appreciate the beauty of such failed theories retrospectively on the condition that we take these background considerations into account. By imaginatively projecting ourselves into the cognitive context of a particular time or place, we may then be able to appreciate the capacity of a theory to elicit an awareness of the power of our intellectual faculties for understanding the world. In this way, we can see the beauty of the Ptolemaic system, for example, even knowing that it does not give a true account of the phenomena. We can appreciate its beauty, for instance, in so far as we recognize its capacity to unify a host of phenomena under a number of general principles that had plausibility against the backdrop of ancient cosmology.

Neither of these cases in which beauty and genuine understanding come apart contradicts the claim that in regarding a theory as beautiful, we express delight in the suitability of our intellectual capacities for making sense of the phenomena. And yet the subjectivist challenge may now appear particularly pressing. How can aesthetic considerations provide a guide to successful theories if they are linked to understanding that may turn out to be mistaken? How can aesthetic considerations be relevant for theory choice if they may also be grounded in an illusory experience of achieving better understanding of the phenomena? If aesthetic judgements indicate only our awareness of gaining understanding, where this awareness may fail to track

truth, then the link between the beauty of a theory and its truth appears contingent after all.

I suggest that even if our awareness of gaining understanding of the phenomena and, by virtue of this, our aesthetic responses do not infallibly indicate the truth of our account of the phenomena, scientists nevertheless have a reason to take aesthetic considerations seriously. This is because providing such understanding is an essential requirement for any successful theory.<sup>14</sup> Moreover, aesthetic judgements are responses to intellectual processes that, while not always tracking genuine understanding, condition the possibility of such understanding. Aesthetic considerations may therefore provide an initial, even if not determining, indicative guide in our search for understanding of the phenomena. In this way, aesthetic considerations can be regarded as having a legitimate pull on scientists despite not being infallibly related to truth.

Thus, when Heisenberg was struck by the beauty of the theory of quantum mechanics that he was in the process of formulating, for instance, he had a reason to follow his aesthetic sensitivity.<sup>15</sup> He had a reason to be guided by the beauty of his theory in so far as his experience of this beauty was an indication of his awareness of growing understanding gained by means of the theory. Whether or not the theory would in the end hold up to its promise could not be inferred from, and had to be determined independently of, its aesthetic appeal. Further (empirical) investigation was therefore required for assessing the truth of the theory. And yet Heisenberg's aesthetic appreciation nevertheless provided a sensory sign of his inkling that by means of the theory he would make progress in understanding quantum processes.<sup>16</sup>

This proposed Kantian account does not tell us how to distinguish good from bad, or reliable from unreliable, aesthetic judgements. It does not formulate criteria for identifying those aesthetic responses that will likely lead to true theories. One may think, moreover, that such criteria will, in the end, depend on the specific nature of the relationship between understanding and truth.<sup>17</sup> A full treatment of the connection between aesthetic judgements and the aims of science will have to provide a detailed account of this relationship. What I have proposed here is

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<sup>14</sup> In Lipton's words (2004, pp. 59ff.), in their search for 'likely' explanations, scientists go for those that are 'loveliest', that is, those explanations that have most potential for providing understanding.

<sup>15</sup> See the example from Heisenberg in the previous section.

<sup>16</sup> The heuristic role I ascribe to aesthetic appreciation is closely related to the function Lipton (2009, p. 59) ascribes to the 'feeling of understanding' when he characterizes it as 'a guide as well as a spur'. The difference between considerations of beauty and the feeling of understanding is that the former but not the latter can be regarded as providing genuinely aesthetic appreciation. Although I do not have space to argue for this here, I believe that it is because of this difference that the proposed conception provides grounds for answering the challenge that considerations of beauty and elegance in science are not genuinely aesthetic (cf. Todd 2008).

<sup>17</sup> In the present context it may be natural to construe the relation between understanding and truth, following Friedman (1974; 1999), for example, on transcendental idealist lines, taking truth to fall out of the ideal end of an ongoing process of gaining understanding. I believe, however, that the proposed account is also compatible with other readings, including realist ones.

that aesthetic judgements may play a legitimate guiding role in science in so far as they are tied to the capacities of understanding which condition our attempts at explaining natural phenomena.<sup>18</sup> It is because of this link of aesthetic judgements to understanding that judgements of beauty do not have to be regarded as entirely contingent responses. And it is this link, moreover, which sheds light on the apparently peculiar fact that, on the one hand, scientists have a reason to be guided in their inquiries by aesthetic considerations, while, on the other, relying on such guidance has also often led them astray.

## V

*Conclusion.* I have proposed construing aesthetic judgements in science as second-order responses to the experienced power of our intellect and the awareness of its suitability for understanding the world. I have argued, moreover, that if aesthetic judgements are understood in this way, we can account for the fact that the historical evidence speaks against a stable connection between beauty and truth, while also explaining why aesthetic judgements have a legitimate appeal for scientists whose aim is to give a true account of the phenomena. The proposed claim is conditional. I do not want to argue that every aesthetic judgement ever made or ever to be made in science is of the kind that fits my proposal. For all I know, scientists and philosophers of science may use aesthetic judgements in very different ways. Instead, I propose that if we understand aesthetic considerations in science as second-order responses to the awareness of the suitability of our intellectual capacities for understanding the phenomena, we can advance debates about aesthetics in the philosophy of science. The proposed Kantian conception of beauty in science, I thus conclude, offers a promising framework for further examination of the nature and role of beauty in science.<sup>19</sup>

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<sup>18</sup> On McAllister's Humean account (1996), too, aesthetic judgements may helpfully guide science. According to his notion of 'aesthetic induction', scientists develop aesthetic responses to empirically successful theories. Aesthetic considerations have a heuristic function, on this account, in so far as scientists regard those accounts as beautiful that show sufficient similarity to empirically successful theories. On McAllister's interpretation, the aesthetic appreciation of the structure of certain theories is a purely psychological compulsion, however. It is this aspect of his theory that raises difficulties in answering the subjectivist challenge. For one should be dissatisfied, I believe, with an explanation of the methodological function of aesthetic considerations that makes this function dependent on scientists' purely contingent and subjective responses to the empirical adequacy of scientific accounts.

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