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A PLEA FOR THE SUBLIME IN SCIENCE

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There is a growing literature on the role of aesthetic values, experiences and judgements in the scientific endeavour. Scientists themselves often profess being guided by aesthetic considerations in evaluating and constructing theories and other scientific artefacts. The focus in the literature, however, is on beauty experiences and aesthetic values typically tied to them, such as coherence, unity and simplicity. The aim of this paper is to broaden and enrich the debate by considering another important aesthetic category, namely the sublime. The latter has been frequently defined in contrast with the beautiful: while beauty experiences are mainly positive and pleasurable, sublimity experiences involve ambivalent feelings (they are disturbing but enlightening at the same time). We shall start by a characterisation of the sublime, which takes into account different philosophical traditions. The discussion shall lead to further examine how beauty and sublimity experiences are related, and why both can be considered aesthetic experiences. Then, we shall turn to the role the sublime may play in science. We shall deal with two sides of this issue: the sublime can be (a) an object of empirical investigation and (b) a guide in the scientific practice. The upshot of our discussion is that although both beauty and sublimity experiences can lead to judgements of truth and understanding, sublimity experiences have a relational nature that makes them apt to ground deep judgements of understanding, about the limits of human cognition.

1. INTRODUCTION

There is a growing literature on the role of aesthetic values, experiences and judgements in the scientific endeavour. The aesthetic dimension of science is suggested by scientists themselves. Indeed, they often describe their objects of study or scientific achievements in terms of beauty, using related adjectives like “harmonious”, “simple”, or “wonderful”. Sometimes they even go further and make direct parallelism between artworks and their theories, laws and experiments. Scientists have also praised their aesthetic sensibility, referring in their decision-making process to emotions and feelings involved in aesthetic experiences (e.g., pleasure, delight, contemplation, exaltation, wonder, awe). Moreover, often enough scientists hold that such aesthetic dimension reveals a connection with the epistemological (and potentially even the ontological) dimension of science: there would be an intimate relationship between beauty and truth.

Aesthetics seems to enter science on at least three different levels:

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(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.

There is arguably a tight connection between the first two levels, not least because the objects of scientific enquiry are often *theoretical* entities. For instance, a theory might inherit aesthetic properties, such as simplicity, order, and coherence, from the fragment of reality that it concerns. The theory would be beautiful because it describes something beautiful. The first two levels belong firmly to the aesthetic domain, but they might provide some kind of justification to the third level. If either the objects or the products of science bear aesthetic values, then aesthetic experiences and judgements about them may be apt to guide the scientific practice, whether in the construction or in the evaluation phase.

Of course, without a clear picture of what aesthetic values, experiences and judgements are, it is hard to assess the real import of aesthetics for science at all these levels. The aim of this chapter is to lay a bridge between recent discussions within naturalised aesthetics (i.e., aesthetics with an eye to producing empirically testable hypotheses) and the debate in philosophy of science on the aesthetic dimension of science.

More precisely, we argue that both literatures have focused almost exclusively on the beautiful and have neglected another important aesthetic category, namely the sublime. The latter can be legitimately considered as belonging to the aesthetic domain, which arguably is variegated and not exhausted by the beautiful. We will show how endorsing such an aesthetic pluralism enriches the debate in philosophy of science.¹

The structure of our discussion is as follows. In Section 2, we introduce the philosophical distinction between the beautiful and the sublime as distinct aesthetic types, which correspond to aesthetic experiences with different cognitive profiles. In Section 3, we address two questions: whether science deals with objects qua bearers of aesthetic values, and whether scientists undergo aesthetic (i.e., both beauty and sublimity) experiences in their endeavour. The discussion will lead to consider that both beauty and sublimity aesthetic experiences have become scientific objects of empirical aesthetics. In Section 4, we turn to the issue of *how* aesthetic experiences and judgements can guide the

¹ On a strong version of aesthetic pluralism, there are at least two distinct *kinds* of aesthetic experiences and properties, such as beauty and sublimity. Weaker versions allow for a continuum between beauty and sublimity, with typical instances of each. Here we stress different cognitive patterns of aesthetic experiences and corresponding properties while being relatively neutral on which version of aesthetic pluralism is correct.

scientist in her endeavour, tackling the influential idea that there is an intimate link between beauty and truth, as well as the emerging idea that aesthetic judgements are rather connected to scientific understanding.² In so doing we shall discuss an influential empirical model of aesthetic experience, which hinges on the notion of processing fluency, and point to its limits in dealing with sublimity experiences. Our claim is that the relational nature of such experiences is such that they can play a specific role, in addition to experiences of beauty, in the construction and evaluation of theories and other scientific products.

2. THE BEAUTIFUL AND THE SUBLIME

A merganser diving in a clear lake, shining patterns made by light reflections on a wall, a colourful countryside landscape, can elicit pleasurable aesthetic experiences. It proves difficult to say why these experiences are aesthetic. Naturalised aestheticians have extensively drawn on empirical research to inform philosophical theories of aesthetic experiences and have put forward very different accounts (for a recent illustration, see Cova & Réhault 2018). Despite their diverging views, naturalised aestheticians tend to agree in thinking that aesthetic experiences, in contrast to non-aesthetic experiences, are characterised by an attentional, self-sustaining or “auto-telic” pattern (see Schaeffer 2015 and Dokic 2016, a similar point is also made in Prinz 2011). The idea is that when we undergo an aesthetic experience, we are motivated to maintain the relation with the object which triggered such an experience, and our motivation is internal to the experience itself. As Kant put it, we linger in the contemplation of the beautiful. This seems precisely what happens in the aforementioned examples.

Contrast the aesthetic experience we can have in admiring the merganser movements or the light reflections with the experience we can undergo when facing the stars in a pure night sky, huge and steep mountains, the primeval force of waterfalls, or the majesty of a T-Rex skeleton. In these circumstances, our experience seems to be tinged with negative feelings, and fear and admiration seem to mix together. There is an overwhelming vastness, or power, which disturbs and unsettles our mind. In his *Lectures on Physics*, Richard Feynman describes the experience of contemplating the stars in a desert night as follows: “The vastness of the heavens stretches my imagination – stuck on this carousel my little eye can catch one-million-year-old light. A vast pattern – of which I am a part” (Feynman *et al.* Ch. 3, §4, fn. 1). We are reminded that we are just human beings confronted with, as Stephen J. Gould would put it, “a majestic entity of such vast spatial and temporal scope that she cannot care

² Ivanova (2017b) stresses three possible different roles played by aesthetic considerations in scientific enquiry, namely a motivational role, a heuristic role and an epistemic role. In §4 we will be mainly concerned with the latter two roles.

much for a little mammalian afterthought with a curious evolutionary invention” (Gould 1991, p. 13). Moreover, despite their negative aspect, these experiences are also the kind of experience that we want to sustain and seek out, that is, they show the auto-telic character proper to aesthetic experiences, thus suggesting that they are indeed aesthetic experiences.

The contrast between these two types of aesthetic experience reveals the variety of aesthetic relationships we can have with the world. Philosophers have captured such a contrast with the distinction between beauty experiences and sublimity experiences (for a recent historical account of this contrast, which is rooted in ancient rhetoric, see Brady 2013). Beauty experiences concern things mentioned in the first examples we gave (a merganser diving, light reflections on a wall, a colourful countryside landscape). Features which have been put forward in order to characterise the objects of beauty experiences include delicacy, smoothness, proportion, fragility, harmony (for discussion, see Scruton 2009 and Levinson 2011). In general, objects of beauty experiences seem to be smaller in size, scope, or power than the objects of sublimity experiences. Thus, beauty experiences lack the overwhelming aspect present in sublimity experiences and, in turn, do not show the negative aspect shown by the latter.³ There is nothing disturbing or unsettling when we are struck by the beauty of a merganser diving. Beauty experiences are mainly positive and pleasurable, are delighting and invigorating, and involve reward and satisfaction. This seems to be true even for cases of so-called “terrible beauty” (see Brady 2013, Ch. 7), that is beauty experiences triggered by more disturbing objects (e.g., a colourful pattern rising on a muddy polluted pond).

The core elicitor of sublimity experiences seems to be vastness. In all the examples of the second type that we offered, there is a confrontation with something that overwhelms us, in size (as the mountains), scope (as the stars) or power (as the waterfalls). Although natural scenes are considered as paradigmatic elicitors of sublimity experiences, arguably also human creations can trigger them. This would be the case, when, for instance, we contemplate the greatness of the Great Wall of China, we stand underneath (or on top of) the Eiffel Tour, or even when we grasp the deep meaning of a scientific theory (e.g., General Relativity).

We have already stressed that the *grandeur* we face in sublimity experiences has a negative effect, given its disturbing and unsettling aspect. Very often philosophers have talked about fear in order to grasp the negative feeling involved in sublimity experiences. The idea might be that it is as if we could foresee a potential danger, though (we judge that) there is no real danger. For instance, the wrath of the waterfalls might turn against us, or we might slide down the steep mountains. However,

³ It is often noted that sublimity experiences involve reverence or admiration, potentially due to their overwhelming aspect (see Keltner & Haidt 2003). That is true, but it might be argued that beauty experiences as well involve feelings of elevation or reverence, though they do not show an overwhelming aspect. Prinz (2011) stresses the importance of these kinds of feeling in aesthetic experience in general.

reference to fear does not seem to capture all examples (see Cochrane 2012). In some cases, we might just feel uneasiness in being confronted with something greater, in time or space, than us (e.g., as in the stars, the T-Rex or the Great Wall of China cases). As suggested by both Feynman's and Gould's remarks, a sense of one's smallness may arise and we may even feel the insignificance of human life. Similarly, in the General Relativity case we may be bewildered by the overturning of our ordinary way to think of time and space, which makes us uncertain about our place in the universe. In addition to the feeling of losing one's grip on these most basic elements of reality, we might experience our smallness or insignificance relative to the genius who achieved such a conceptual revolution. Our confrontation with a theory manifestly designed by a mind so much greater than ours may have the disturbing effect on ourselves which is characteristic of sublimity experiences.

However, the greatness we are confronted with has a positive effect too. It raises a challenge to our mind, which is enlightening and elating. Our senses, intellect and imagination have to "stretch" (to echo Feynman's quote) themselves to handle, for instance, immense expanses, a myriad of objects, overpowering forces, astonishing achievements. Shortly after the given quote, Gould says: "Thus, I love nature primarily for the puzzles and intellectual delights that she offers to the first organ capable of such curious contemplation" (Gould 1991, p. 13). Similarly, Joseph Addison wrote: "Our Imagination loves to be filled with an Object, or to grasp at any thing that is too big for its Capacity" (1712). It has been underlined that sublimity experiences seem to disclose new levels of knowledge, or even reality. Supernatural values, as Kantian philosophy suggests, or the essence of the universe and the natural forces that govern it, as it emerges in Schopenhauer's view (Schopenhauer 1819/1844), might be revealed by sublimity experiences. The German term for "sublime" is precisely "Erhabene," which is etymologically tied to the noun "Erhebung" meaning elevation. It is not surprising that the experience of the sublime has been associated with spiritual or mystical experiences.

The positive aspect of sublimity experiences shows that they bear some similarities with beauty experiences. Notwithstanding the double aspect (positive and negative) of the sublime, arguably its overall valence is positive. Perhaps it is not accurate to talk about pleasure to capture such a positive valence – Kant stressed that the sublime seems to involve a kind of pleasure "that is only possible by means of a displeasure" (Kant 1790, §27). As stressed beforehand, it is obviously not the kind of experience that we want to cease to have. On the contrary, we want to keep it alive as long as possible or to reproduce it, as in the case of beauty experiences.

We have ended up with a rough idea of what an aesthetic experience is, and of its two varieties, corresponding to different cognitive patterns (involving sensory, attentional, emotional, and intellectual aspects), namely beauty and sublimity experiences. Let us also assume that these

two patterns correspond to different aesthetic properties or values (as our examples below will make clear). In the following sections we will look more closely at the impact of this picture on the aesthetics of science.

3. AESTHETIC OBJECTS OF SCIENTIFIC ENQUIRY

The speed of light, the structure of DNA, the nature of Gravity, mammalian evolution, mathematical constants, etc. are all objects of scientific enquiry diverging in scale and scope, but can we find a common denominator? More precisely, given our focus in the present context on the aesthetic dimension of science, could we say that science deals with objects qua bearers of aesthetic values? The idea might even be pushed further, and it might be suggested that scientific objects show aesthetic values and these very values capture the scientist's attention leading her to study those objects. Scientists' reports of their practice hint at such an idea. Aesthetic values such as harmony, regularity, coherence, unity and simplicity are often invoked by scientists as possessed by the objects under scrutiny and driving their enquiry. (As we have observed in the introduction, such values can also be instantiated, perhaps by inheritance, by the scientific constructions themselves, namely theories, hypotheses, models, etc.)

This is a vexed issue. Strong sceptics claim that when talking about aesthetic values scientists are not really referring to properties they are acquainted with, but rather merely employing metaphorical language. It would be a sort of confabulation which hides other values or reasons (e.g., pragmatic or epistemic) behind aesthetic language. Leaving aside such a view and granting that scientific objects have aesthetic values, there is another pressing worry concerning what aesthetic values are relevant in the scientific domain. They might depend on the specific discipline. Physicists and mathematicians often praise aesthetic values like regularity and simplicity, but irregularity and complexity can also be seen as important aesthetic values shown by scientific objects. This is clearly seen if we turn, for instance, to biology (Ivanova 2017b), but even to specific branches of Physics itself (e.g., Quantum Theory). Moreover, even within the same scientific discipline different levels of enquiry can show different aesthetic values. For instance, electricity might be seen as bearing different aesthetic values in different contexts (e.g., when conducting an experiment and when developing a theory).

To add a further layer of complexity, aside from the issue of scientific objects qua bearers of aesthetic values, we might ask whether in developing theories or studying phenomena scientists undergo aesthetic experiences. Again, scientists' reports point in that direction. Albert Einstein, for instance, said that: "The fairest thing we can experience is the mysterious. It is the fundamental emotion that stands at the cradle of true art and true science" (Einstein 1934/1935, p. 5 – see also

Einstein 1932). Although Einstein is not explicitly talking about an aesthetic experience as such, he is referring to a kind of experience which, on his view, is crucially involved in both art and science. Other scientists have compared the experience triggered by the confrontation with art to the experience triggered by the confrontation with science. To give an example, “Mathematics, rightly viewed, possesses not only truth, but supreme beauty”, wrote Bertrand Russell (Russell 1919, p. 60). The aside “rightly viewed” suggests that what matters is the perspective, the experience that the subject is undergoing in being confronted with mathematics. The hypothesis that the aesthetic experiences mathematicians and artists have described with similar words are very close, if not the same, has been recently investigated by neuroscientists.

Aesthetic experiences themselves can be the object of scientific scrutiny. A new trend in aesthetics is empirical aesthetics, which attempts to understand aesthetic experiences at the neurological level. An experimental study conducted by Semir Zeki and colleagues (2014) directly investigates the neural correlates of mathematical beauty. Drawing on previous data on the neural correlates of beauty experiences elicited by visual and musical stimuli and recording neural activity by means of functional Magnetic Resonance Imaging (fMRI), Zeki and colleagues show that the same brain area is activated when mathematicians are presented with mathematical formulae.⁴ These findings offer important insights into the nature of aesthetic experiences and (assuming that we can generalise to other sciences) lend force to the idea that scientists’ talking in aesthetic terms should be taken literally as referring to aesthetic experiences.

Both the debate over aesthetic values in science and the debate over aesthetic experiences in scientific practice focus exclusively on beauty experiences and aesthetic values typically tied to them, such as coherence, unity and simplicity. However, the topic of the sublime and the aesthetic pluralism we are endorsing sheds new light on both issues.

First, we have seen that, although scientists praise aesthetic values like regularity and simplicity more often than values like irregularity and complexity, the question is not settled, since the latter can also matter aesthetically. Moreover, note that such a tension between aesthetic values pulling in opposite directions raises a genuine concern only if we think that they belong to the same aesthetic type. However, it might be claimed that while values like regularity and simplicity are tied to the beautiful, values like irregularity and complexity are more characteristic of the sublime, given its disturbing, unsettling and challenging aspects. Therefore, acknowledging that the aesthetic domain

⁴ Judgements of beauty have been repeatedly reported activating medial prefrontal cortex, encompassing both the medial orbitofrontal cortex (mOFC) and the rostral anterior cingulate cortex (rACC), for paintings (e.g., Kawabata & Zeki 2004; Ishizu & Zeki 2011), music (Ishizu & Zeki 2011). The pivotal role of the mOFC has been supported by a meta-analysis of neuroimaging studies (Brown, Gao, Tisdelle, Eickhoff and Liotti 2011). Indeed, positive aesthetic judgement about stimuli from different sensory modalities (vision, audition, gustation and olfaction) recruited partially overlapping portions of this brain region.

encompasses more than the beautiful opens up new paths of inquiry in the domain of aesthetic values involved in science.

Second, it seems also promising to give room in science for sublimity experiences as genuine aesthetic experiences along with beauty experiences. It is striking to notice that scientists themselves use words evocative of sublimity experiences when they describe their scientific experiences. Einstein (1932), for instance, talks about the “mysterious” as “the most beautiful experience” grounding “all serious endeavour in art and science”. But arguably the mysterious can be tied to sublimity experiences, given that they involve a confrontation with a greatness, which overwhelms and bewilders us, in a way which challenges our mind and eventually enlightens us. Einstein goes on and describes the mysterious as follows: “To sense that behind anything that can be experienced there is a something that our mind cannot grasp and whose beauty and sublimity reaches us only indirectly and as a feeble reflection”. Here the fact that in sublimity experiences our mind is prompted to cope with a grandeur beyond its own power, the overwhelming aspect of sublimity experiences, is explicitly stressed. Moreover, Einstein thinks that the mysterious underlies also religion, and as we have observed, sublimity experiences have been associated with spiritual experiences.

Other telling words come from Richard Feynman, when he comments on James Watson’s report of what he experienced during the DNA structure discovery. He writes:

Is the sudden transformation of all the relevant scientific characters from petty people to great and selfless men because they see together a beautiful corner of nature unveiled and forget themselves in the presence of the wonder? (...) But when you describe what went on in *your* head as the truth haltingly staggers upon you and passes on, finally fully recognized, you are describing how science *is* done. I know, for I have had the same *beautiful* and *frightening* experience. (Feynman 2005, To James D. Watson, February 10, 1967 – the latter two italics are ours)

In this passage we retrieve the double, positive and negative, nature of sublimity experiences. Feynman also hints at wonder, which is another emotion frequently associated with the sublime, and with aesthetic experiences in general (Prinz 2011).⁵

Similar words can be found in Michael Faraday’s description of his emotional state when engaged with experiments on Gravity:

I have been arranging certain experiments in reference to the notion that Gravity itself

⁵ The following passage from John F. W. Herschel illustrates the role of wonder in the scientist’s experience but also its self-sustaining character: “Accustomed to trace the operation of general causes and the exemplification of general laws, in circumstances where the uninformed and unenquiring eye *perceives neither novelty nor beauty, he walks in the midst of wonders* (...). Nor is it a mere passive pleasure which is thus communicated. A thousand questions are continually arising in his mind, a thousand subjects of enquiry presenting themselves, *which keep his faculties in constant exercise, and his thoughts perpetually on the wing*” (Herschel 1852: 15 – italics ours).

may be practically and directly related by experiment to the other powers of matter and this morning proceeded to make them. It was almost with a *feeling of awe* that I went to work, for if the hope should prove well founded, how great and mighty and sublime in its hitherto unchangeable character is the force I am trying to deal with, and how large may be the new domain of knowledge that may be opened up to the mind of man. (Faraday V, 156 – our italics)

Faraday here is pointing at the enlightening and elating aspect of sublimity experiences, due to the challenge our mind is called to face. The reference to the feeling of awe, however, suggests that such a positive experience is tinged with a negative feeling. It is difficult to define what awe is. Interestingly in some languages other than English there is no one-word translation of awe and an expression conveys its positive and negative components. For instance, in French “awe” can be rendered by a complex phrase meaning something like “fear mixed with admiration” (“effroi mêlé d’admiration”). Psychologists have mentioned awe as the specific emotion triggered by the sublime. For instance, in their comprehensive review of studies about awe in different theoretical domains (e.g., psychology, philosophy, religion, and sociology), Dacher Keltner and Jonathan Haidt (2003) explicitly mention the connection between the philosophical concept of the sublime and awe, and propose as prototypical aspects of the latter vastness and need for accommodation, which echo power and obscurity (in the metaphorical sense of being difficult to grasp by intellect) in Burke’s definition of the sublime.

Keltner and Haidt’s work shows that sublimity experiences themselves can be the object of scientific enquiry. This is extremely important, because only by getting clear on the nature of sublimity experiences we would be in the position to clarify whether scientists are indeed reporting a sublimity experience when using sublime-related vocabulary. In such a way we would keep at bay sceptical stances according to which such a vocabulary is either merely metaphorical or empty (Todd 2008).

Empirical aesthetics seems to be well placed to offer important insights into the mechanisms that allow us to undergo sublimity experiences. However, although there is a growing body of work in this field, this approach seems to have conflated aesthetic experiences with beauty experiences, since it has produced abundant data mostly on the neural correlates of the latter. A notable exception is an experimental study conducted by Tomohiro Ishizu and Semir Zeki (2014), which directly investigates the neural correlates of the sublimity experience. In line with the philosophical picture, Ishizu and Zeki found: the activation of brain areas corroborating the double (positive and negative) nature of sublimity experiences, a weak correlation with pleasantness, but a strong correlation with grand scale. However, their findings diverge from the philosophical literature on two points. First, in their study Ishizu and Zeki have found that sublimity experiences do not activate the areas active during beauty experiences. For this reason, they take sublimity experiences to be non-aesthetic. Second, their neuroscientific

findings suggest that experience of the sublime involves suppressed or at least diminished self-reflection. This is in contrast with the philosophical idea that this experience is self-centred, being frequently associated with the feeling of the insignificance of human life, of our own smallness compared to the *grandeur* we are confronted with.⁶

Both points are not as problematic as they may seem at first sight. First, though Ishizu and Zeki's neuroimaging findings did not show the recruitment of overlapping brain structures between sublimity and beauty experiences, this comparison was made on the basis of results concerning two different studies employing quite different material. In the study on sublimity, stimuli consisted in (pictures of) natural scenes, while in the study of beauty, (pictures of) paintings were employed. Although of course more philosophical work is needed to characterise more precisely what aesthetic experiences are, their results are fully compatible with the ontological view that sublimity and beauty experiences are two species of the same genus, viz. aesthetic experience. Thus, to date, no firm conclusion could be made on this issue.

Second, an account can be offered of how the self is involved in the sublimity experience that accommodates both the empirical observation that such experience involves decreased self-focused attention (recall Feynman's words: scientific endeavour makes scientists forget "themselves in the presence of the wonder") and the claim that they are self-centred (giving rise to the sense of one's own insignificance or smallness). Arguably while beauty experiences are rather object-centred, sublimity experiences seem to be much more self-centred. The latter seem to result from irreducibly relational properties involving the subject's self and her immediate environment (e.g., not just the *Garganta del Diablo*, but these waterfalls in comparison with one's smallness).⁷ In contrast, the features that are responsible for beauty experiences are (at least mostly) in the beautiful things themselves (e.g., harmony, simplicity and symmetry are perceived as objective rather than subjective features). However, this does not mean that when we undergo a sublimity experience we are aware of the self-relative properties which trigger such an experience. When the subject feels the majesty and power of Iguazu Falls, she tends to consider the waterfalls themselves as the object of her experience, without any apparent contribution of the self, while in fact it concerns herself in relation to the immediate environment.

Putting things this way echoes what Kant said about sublimity experiences. He claimed that

⁶ Although their study undoubtedly offers important insights into the nature of the sublime, Ishizu and Zeki's findings should be taken with caution for two main methodological reasons (see Arcangeli, Dokic & Sperduti 2018). First, the study's experimental setting is fragile: pictures of natural scenes presented on a computer screen within a scanner are clearly limited in their grandeur and capacity as triggers of sublimity experiences. Second, the authors' comparison with the case of beauty appeals to a quite different experimental material, involving paintings rather than natural scenes.

⁷ The *Garganta del Diablo* is a set of waterfalls (80m high) that fall into a narrow canyon, which concentrates the largest flow of the Iguazu Falls, being in turn these falls (located on the Argentina-Brazil border) the largest flow in the world.

sublimity “is not contained in anything in nature, but only in our mind” (Kant 1790, §28), thus suggesting that this type of experience appears to be object-centred, but in fact concerns only the human mind. Against a radical take on experiences of the sublime, which puts too much emphasis on the subject side, we have proposed (see Arcangeli, Dokic & Sperduti 2018) a less radical account without falling prey to the opposite radicalism, which pays too much attention to the object side and underestimates the subject side.⁸ Sublimity experiences can be self-centred at the *ontological level* (i.e., their objects are relational properties essentially involving the self), but object-centred at the *phenomenological level* (i.e., subjects “forget themselves” and attribute sublimity exclusively to the environment).

On this view, the decreased self-focused attention found by Ishizu and Zeki can be explained by the fact that sublimity experiences, contrary to beauty experiences, have implications for the status of the self, insofar as they are ontologically more self-centred than beauty experiences. The pressing question is why phenomenologically the self seems to disappear. Our tentative hypothesis is that we have decreased self-focused attention, because sublimity experiences are immersive, they tend to blur the phenomenological boundary between the self and the world. The sublime overwhelms us, to the point that we lose ourselves in it.

All these considerations highlight the importance of the aesthetic category of the sublime, and lay also the basis for fruitful interdisciplinary research, which is very much needed to get clear on the nature of the sublime and on its role in science. As stressed beforehand Ishizu and Zeki’s study is the first experimental study on the sublimity experience in the psychological domain. It only considers paradigmatic elicitors of such an experience, namely natural scenes, without taking into account other elicitors, such as artworks or scientific objects. Thus, the psychological literature neglects the role that sublimity experiences might play in scientific practice. In the following section we would like to focus on how aesthetic experiences can intervene in scientific activities with an eye to both beauty and sublimity experiences.

4. AESTHETIC EXPERIENCES IN SCIENTIFIC PRACTICE

4.1 The fluency-based account in psychology

Why should aesthetic considerations be relevant to the scientific practice? Traditional answers to this question point to ontological connections between aesthetic and epistemic values. Consider

⁸ Kant’s theory has been considered, for instance, as “radically subjective” (Shapshay 2014, p. 96) or as an “egoistic model” of the sublime, which ignores “the distinctly other-directedness of the sublime experience” (Cochrane 2012, p. 13). Tom Cochrane puts forward a model in which sublimity experiences are primarily object-centred and involve a sense of self-negation.

the venerable Platonic view that beauty and truth are the same. On this view, theories (hypotheses, conjectures, etc.) endowed with aesthetic properties, such as simplicity, elegance, symmetry, etc., would also be true. A view which is slightly less strong has it that beauty at least partly constitutes truth: theories that lack aesthetic properties cannot be true.

Interesting epistemic *norms* can be grounded on such ontological connections. If truth is or entails beauty, then, as Feynman puts it, “you can recognize truth by its beauty and simplicity” (quoted in Schwartz 2018). On this view, evidence that a theory is beautiful is also at least partial evidence that it is true. Specific aesthetic properties can guide the scientists to the truth of their theoretical constructions, either when they are developing or evaluating them. For instance, faced with extensionally equivalent but internally different theories, the scientist *should* believe, or would be *justified* in believing, the more simple or elegant one. More generally, we are at least *prima facie* justified in accepting (or rejecting) a theory because of its positive (or negative) aesthetic properties.

Independently of the existence of such epistemic norms, a psychological question arises as to whether scientists actually use psychological *heuristics* or “rules of thumb” connecting the pursuit of truth with aesthetic experiences and judgements. For instance, a theory that is assessed as beautiful, or more beautiful than another theory, will also be judged to be more truthful or faithful to the facts. The scientist’s psychological assessment can be implicit or explicit. In the former case, she is biased toward beautiful theoretical constructions but is not necessarily aware of this bias. In the latter case, her assessment will typically take the form of an aesthetic judgement: a theory that is *judged* to be beautiful will also be judged to be true.

Note that the psychological question does not entail that the existence of genuine epistemic norms grounded on ontological connections between beauty and truth. Even if aesthetic values do not exist or do not give rise to genuine epistemic norms, it might be that, as a matter of fact, scientists use aesthetic assessments to build and evaluate theories, hypotheses, etc. Richard Feynman’s claim can of course be interpreted in the epistemological sense (beauty is an epistemic norm because it co-varies with truth), but it might also be the expression of a mere psychological heuristic: “Believe only what is beautiful (*ceteris paribus*)”.

The psychological interpretation is empirically testable. Consider the fluency-based account of judgements of beauty and truth (for a recent statement, see Schwarz 2018). The core idea of this account is that “judgements of beauty and judgements of truth share a common characteristic: people make them, in part, by attending to the dynamics of their own information processing” (p. 25). The relevant dynamic features have to do with so-called “processing fluency”. Some psychological processes are more fluent than others. For instance, it is easier for the visual brain to process the face of a friend than that of a stranger. Likewise, a long and complex sentence will be

difficult to process in contrast to a short and simple one. Processing fluency is something that can transpire at the conscious level. There is more to the phenomenology of perceiving or thinking than what is perceived or thought. More precisely, processing fluency can be *felt*. Our friend's face feels familiar, unlike the stranger's. A long and complex sentence feels difficult to parse and to understand, in contrast to a short and simple one, etc.

Now there is some empirical evidence that processing fluency is the source of at least some judgements of beauty (Reber 2012; Reber & Bulot 2013). For instance, a visible shape will be judged more beautiful than, or aesthetically preferable to, another visible shape if the former is easier to process than the latter. Ease of processing may be due to intrinsic features of an object, such as its simplicity, symmetry, balance, clarity, contrast, etc., but also to whether the subject is used to process the object. According to the so-called "mere exposure effect" (Zajonc 1968), the more we perceive an object, the more we like it: mere exposure to the object can make it appear more beautiful, or at least aesthetically agreeable.

Interestingly, it seems that processing fluency is also the source of at least some judgements of truth. When a sentence is easy to process, the subject will tend to judge it true (absent other information on the subject-matter). Moreover, the mere exposure effect can work for judgements of truth as well. *Ceteris paribus*, the more we are confronted with a rumour, the more we tend to accept it as true (Allport & Lepkin 1945, cited in Schwartz 2018). According to the fluency-based account, any parameter that increases the ease with which an object is processed should also increase the likelihood that the object is experienced as beautiful or accepted as true.

Let us assume, then, that some judgements of truth and some judgements of beauty are psychologically rooted on the same type of feeling, having to do with the dynamics of our own information processing. Does it follow that aesthetic experiences and judgements guide the scientific practice? The implication is not straightforward. Note that the way the feeling of fluency is spontaneously interpreted by the subject is a matter of contextual variation. Depending on the context, such feeling can evoke either mere ease of processing, familiarity, truth or beauty. The scientist who is building or evaluating a theory might just manifest a general preference for fluent processing without having any aesthetic experience as such. In other words, feelings of fluency might guide the scientific practice independently of whether they are interpreted as aesthetic experiences and feed spontaneous aesthetic judgements. Moreover, it is not clear that a particular feeling of fluency can be *simultaneously* interpreted as a feeling of truth and as a feeling of beauty. In general, feelings of fluency get an aesthetic interpretation, and feed spontaneous judgements of beauty, only if the subject is *ignorant* about the cause of fluency (Reber 2012). For instance, the mere exposure effect works only if the subject does not know that processing fluency has been

enhanced by mere repetition. When the subject is aware of the cause of fluency, her feeling of fluency is interpreted as simple familiarity with the object. Thus, what counts as an appropriate context for a feeling of fluency to feed a spontaneous aesthetic judgement might not count as appropriate for it to feed a spontaneous judgement of truth.

Still, we can argue that a two-step mechanism can connect the fluency-based account with the claim that aesthetic experiences and judgements guide the scientific practice. The first step of the mechanism is the subject's implicit realisation, across several contexts, that the same type of feeling underlies both judgements of beauty and judgement of truth. The second step is the interiorisation of a heuristic connecting beauty and truth, something like "If it feels beautiful, it must be true". The point of the heuristic is to *extend* one's ability to form judgements of truth. Judgements of truth can be based on feelings of truth (i.e., on feelings which in the relevant context are interpreted as truth-conducive), but thanks to the heuristic, they can also be based on feelings of beauty. The fluency-based account explains the first step of the mechanism, and thus contributes in part to the explanation of the more general claim that aesthetic experiences and judgements guide scientific practice.

As it stands, the heuristic "If it feels beautiful, it must be true" is a mere feeling-based psychological shortcut. Can it be elevated to a general epistemic norm connecting truth and beauty? The answer depends on whether processing fluency can be said to track both truth and beauty. As we have observed, processing fluency is a function of objective properties, such as simplicity, symmetry, order, etc., but it is also the function of subjective properties, such as whether and to what extent the subject has processed the object, or similar objects, in the past. The hard question is whether such idiosyncrasy is compatible with the claim that processing fluency is a reliable sign of both truth and beauty.

The fluency-based account points to a common psychological core of judgements of beauty and truth, but as many authors have suggested (including Ivanova 2017b and Breitenbach 2013), aesthetic considerations may aid scientific *understanding* rather than truth. The ordinary notion of understanding is truth-independent: for instance, one may understand a sentence (such as "There is life on Alpha Centauri") even if we do not know whether it is true or false. However, there might be a deeper notion of understanding as involving "an ability to grasp how the facts fit together" (Ivanova 2017b, p. 6). On this notion, understanding a theory is more than just understanding the syntax and semantics of each sentence constituting it. Rather, it demands that we grasp the theory as a unified relational whole beyond the separate contributions of its components. It is controversial how the deeper notion of understanding relates to truth and to knowledge. One view is that understanding in this sense *entails* truth. A less radical view is that it is at least *truth-conducive*:

deep understanding (from now on, just “understanding”) would thus be a symptom of truth. Independently of this controversy, the fluency-based account can easily be extended to judgements of understanding (or at least some of them; see below). The notion of understanding has been related to values such as coherence, unity, and simplicity, which are correlated with processing fluency at the psychological level. It is perhaps not an accident, then, that some judgements of understanding, whether or not they also involve judgements of truth, can have common roots in processing fluency as spontaneous aesthetic judgements of coherence, unity, and simplicity.

4.2 The heuristic role of sublime: disfluency

The fluency-based account is about judgements of beauty, but what about the sublime? It is widely agreed that our experience of the sublime crucially hinges on negative emotions, either fear or terror, or a more general affective experience such as a “feeling of self-negation” (Cochrane 2012). It seems to follow that sublimity experiences are associated with *disfluent* rather than fluent processing, which nonetheless eventually leads to aesthetic pleasure. Recall Burke’s famous contrast between beauty and sublimity:

For sublime objects are vast in their dimensions, beautiful ones comparatively small; beauty should be smooth, and polished; the great, rugged and negligent; beauty should shun the right line, yet deviate from it insensibly; the great in many cases loves the right line, and when it deviates, it often makes a strong deviation; beauty should not be obscure; the great ought to be dark and gloomy; beauty should be light and delicate; the great ought to be solid, and even massive. (Burke 1759, p. 113)

It is clear from this passage that beauty experiences are on the side of fluency whereas sublimity experiences are on the side of disfluency. Typically at least, small, smooth, polished, light and delicate objects are processed fluently, but rugged, negligent, dark, gloomy and powerful objects are processed disfluently.

Defenders of the fluency-based account can envisage at least two strategies in order to deal with the sublime as an aesthetic category. The first strategy is *restrictive* and insists that the domain of the account is limited to a specific category of aesthetic mental phenomena, namely experiences and judgements of beauty. On this view, sublimity experiences and judgements should be the topic of another, quite different account. Any such account would have to accommodate the apparent asymmetry between fluency and disfluency regarding their aesthetic interpretation. On the fluency-based account, fluency intrinsically feels good, and thus is apt to feed spontaneous aesthetic judgements (of beauty). In contrast, disfluency does not feel so good (it is generally a signal that something is novel, or wrong), so that it is much less clear how they could feed spontaneous

aesthetic judgements (of sublimity). There does not seem to be a simple analogue of the fluency-based account in the case of sublimity experiences and judgements.

A more ambitious strategy would try to accommodate the sublime within the scope of the fluency-based account. Bulot & Reber (2013) propose a distinction between perceptual and conceptual fluency and claim that cases of aesthetic experience in which disfluency is involved (which may or may not involve the sublime) are always, eventually, conceptually fluent. For instance, Bridget Riley's paintings are clearly *visually* disfluent and yet *conceptually* fluent to the extent that the mind enjoys reflecting on its own contribution to the perceptual experience of the world. In the specific case of the sublime (which they do not discuss as such), the authors' view could be that our aesthetic experience is at least conceptually fluent, although it is strongly disfluent at lower (perceptual and affective) levels. Indeed, as some of our previous scientific examples illustrate, in having a sublimity experience, the mind enjoys reflecting on the limits of perception, imagination and standard frames of reasoning. As Keltner & Haidt (2003) put it in Piagetian terms, sublimity experiences involve a "need for accommodation", i.e., an urge to go beyond standard frames of reference insofar as they have become useless to deal with the greatness of the sublime.

The ambitious strategy might underestimate the role of disfluency as a causal determinant of spontaneous aesthetic judgements. Disfluency is not a dispensable component of the whole affective experience that is supposed to feed such judgements, over which fluency eventually wins. As was noted above, fluency feeds judgements of beauty only if the subject is *ignorant* of the source of fluency. More precisely, the subject may form a judgement of beauty if she feels fluency but also some uncertainty as to the source of the fluency. The latter feeling of uncertainty involves processing *disfluency*. Thus, the whole affective experience that feeds the subject's spontaneous judgements of beauty involves both fluency and disfluency (see Dokic 2016). In the case of the sublime, the disfluency is presumably stronger, since it is associated with a disturbing limit-experience, in which the mind faces some of its own cognitive boundaries and limitations. Yet, the mind somehow overcomes or accommodates this limit-experience, giving rise to a pleasurable experience. In a nutshell, any aesthetic experience, whether about something beautiful or sublime, involves a proper balance of fluency and disfluency, compatible with overall aesthetic pleasure.

With this admittedly schematic picture of aesthetic experience in mind, let us come back to the claim that aesthetic considerations guide the scientific practice. We have seen how a subset of these considerations, namely those which pertain to beauty and its symptoms (such as simplicity, elegance, symmetry, etc.) may guide the scientist to judgements of truth and understanding. What about aesthetic considerations having to do with the sublime? Can they guide the scientific practice too? If so, what are the non-aesthetic judgements that they motivate?

We have already stressed (§3) the importance given by scientists to values such as complexity and irregularity. It is interesting to note that when he comments on the role of beauty in science, Poincaré seems to point to a distinction between two types of aesthetic considerations:

And it is because simplicity, because vastness, is beautiful that we seek by preference simple facts and vast facts, that we take delight, now in following the giant courses of the stars, now in scrutinising with a microscope that prodigious smallness which is also a vastness, and now in seeking in geological ages the traces of a past that attracts us because it is far away (Poincaré 1908, p.16)⁹

In this passage, Poincaré observes how the scientist is motivated to study “vast facts” [les faits grandioses], even though cognition of greatness typically involves disfluency rather than fluency. Great facts are mathematical, spatial, temporal or dynamic facts that defy our standard schemes of thought and reasoning. Again, great facts call for accommodation, and challenge the scientist to find radically novel ways of theorising about the world.¹⁰

One can surmise, then, that spontaneous judgements of sublimity can enter heuristics which draw the scientist’s attention to highly challenging phenomena and domains of enquiry. Such judgements can also contribute to our spontaneous evaluation of a theory as innovative. It does not follow that processing disfluency by itself is relevant to scientific practice. As we have observed, too much disfluency signals confusion, and diverts rather than draws and maintains attention. However, processing disfluency against a background of processing fluency may be the symptom that we have arrived at a theory whose explanatory value is radically novel while the components of the theory are familiar.

We have suggested that the objects of sublimity experiences are more relational than the objects of beauty experiences. While the latter seem to point to intrinsic features of the beautiful objects, the former are essentially about our own cognitive relationship with the world. The relational structure of sublimity experiences can then provide another route to understanding.¹¹ We have seen how values such as simplicity, unity, elegance, etc., which are correlated to fluency at the psychological level, can guide the scientist to judgements of understanding (which may or may not be accompanied by judgements of truth). We now see that aesthetic considerations pertaining to sublimity can also motivate the scientist to form other judgements of understanding, which involve

⁹ The original French terms “grandeur” and “grandiose” are differently translated in English. “Vastness” and “vast” are employed by Francis Maitland in his translation of *Science and Method* (1914, London: T. Nelson). “Grandeur” and “sublime” are preferred by George Bruce Halsted (see *The Foundations of Science: Science and Hypothesis, The Value of Science, Science and Method*, 1913, New York: The Science Press).

¹⁰ See again Herschel’s quotation in footnote 4.

¹¹ See also Ivanova (2017a). We take on board her claim that Poincaré links beauty to scientific understanding (i.e., revealing “hidden kinships” and “real relations” in the phenomena). We are suggesting in addition that the sublime may be relevant too, and that Poincaré seemed to acknowledge the distinction between beauty and sublimity.

the feeling that the theory or set of hypotheses under consideration has been pushed towards the limits of what we may cognitively encompass as human beings. This is what happens when, for instance, we grasp the deep meaning of General Relativity. Sublimity experiences are limit-experiences, but limit-experiences also play a role in the pursuit of understanding, which again may point to a common psychological core.

5. CONCLUSION

In this paper, we have tried to clarify the relevance of aesthetic considerations to science. We have distinguished three levels at which such considerations might apply: the level of the objects of scientific inquiry, the level of the scientific constructions (theories, hypotheses, models, etc., but also experimental settings), and the level of the scientific practice (constructing and evaluating theories, etc., and designing and conducting experiments).

We have endorsed aesthetic pluralism, in particular the idea that the aesthetic domain encompasses not only the beautiful, but also the sublime. The aesthetic category of the sublime has been largely neglected in discussions of the relationship between aesthetics and science, but we have shown that scientists themselves have often pointed to aesthetic properties and values pertaining to the sublime. Vast facts and thought-provoking theories might trigger sublimity more than beauty experiences. We have given several illustrations of how aesthetic experiences and judgements, about scientific objects or constructions, guide the practice of scientists in different ways, depending on whether they belong to the beautiful or the sublime.

The claim that aesthetic considerations can guide the scientific practice might be grounded on deep ontological connections between aesthetic and epistemic values, having to do with truth, justification, and understanding. Independently of such connections, about which we can remain relatively neutral here, this claim can also be grounded on a theory of aesthetic experience as being constituted by epistemic feelings and emotions. Aesthetic experience has to do with surprise, interest, curiosity, perplexity, etc., which are variations on the themes of familiarity and novelty. An aesthetic object cannot be too familiar, on pains of being boring, and it cannot be too novel, on pains of being confused. Arguably, the very same epistemic values pervade the scientific practice, and guide the scientist to the elaboration and evaluation of a theory whose conclusion may be novel while the building-blocks of the theory are familiar. As the beautiful and the sublime involve different blends of familiarity and novelty, it is not an accident that the complex feelings underlying spontaneous judgements of beauty and sublimity play differentiated roles in the epistemic heuristics used by the scientist. Some aspects of a theory may strike us as being beautiful because of the way

it articulates something with which we were already familiar, and other aspects of the theory may strike us as being sublime because it points to something entirely novel and deep. Familiarity and novelty form the common core of aesthetic and epistemic values, and this explains why considerations that are aesthetically relevant can also be epistemically relevant to theory building and evaluation.

More specifically, we have shown that aesthetic considerations can feed not only judgements about the truth or correctness of scientific theories (hypotheses, etc.), but also judgements of understanding. Although beauty can guide the scientist to some judgements of understanding having to do with the internal structure of theories, we have suggested that sublimity may be responsible for further judgements about the limits of human understanding. More generally, we surmise that the relational nature of sublimity experiences makes them apt as a guide to relational knowledge, which seems crucial for scientific understanding.

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