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Beauty in science: a new model of the role of aesthetic evaluations in science

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Abstract In *Beauty and Revolution in Science*, James McAllister advances a rationalistic picture of science in which scientific progress is explained in terms of *aesthetic* evaluations of scientific theories. Here I present a new model of aesthetic evaluations by revising McAllister's core idea of the aesthetic induction. I point out that the aesthetic induction suffers from anomalies and theoretical inconsistencies and propose a model free from such problems. The new model is based, on the one hand, on McAllister's original model and on further developments by Theo Kuipers in his "Beauty, a Road to the Truth?". On the other hand, it is based on empirical findings about affection and emotion, and a naturalistic aesthetic theory. The new model is thus a naturalistic model with a wider explanatory range and much more internal consistency that McAllister's.

Keywords Beauty in science · Aesthetic induction · Aesthetic evaluations in science · Aesthetics and science · Affection · Emotion

1 Introduction: aesthetic evaluations and aesthetic induction in science

Science and art seem alien to each other. Science is a rational discipline that deals with objective facts. Art is subjective and deals with the subjective realm of emotions. Science is concerned with empirical evaluations of the world, whereas art with aesthetic ones. But consider this evaluation by Steven Weinberg: "Einstein's general theory of relativity […and…] Newton's theory of gravity […] are equally *beautiful*"

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(Feynman and Weinberg 1999, p. 107). Or this one: "[…] most physicists find the Standard Model unappealing because it is exceptionally *ugly* […]" (Kaku and Thompson 1997, p. 75). Aesthetic evaluations of scientific theories are very common and they constitute a perplexing intrusion of the irrational into science. Even more perplexingly, prominent scientists, Paul Dirac (1980, p. 10) for example, have endorsed the idea that the beauty of theories plays a significant role in the progress of science. This, however, is not the most prominent intrusion of irrationality into science. Schools of philosophy of science such as relativism or post-modernism challenge the very idea that science is rational. The nature of scientific revolutions constitutes the core of the standard argument against the rationality of science (Newton-Smith 1981; Cohen 1985; Nickles 2003). However, in *Beauty and Revolution in Science* (1996) James McAllister defends a rationalistic view of science that accounts for both aesthetic evaluations and scientific revolutions. The notion of *aesthetic induction*, a mechanism that links empirical and aesthetic evaluations of theories through an inductive relation, is central to that account. In the aesthetic induction the track record of empirical success of theories bearing certain properties induces an increase in preference for those properties. My goals in this paper are, first, to show that a better model of the aesthetic induction is needed and, second, to provide such a model.

There is a vast literature compiling the history and variety of aesthetic concerns in science, most of it consisting of historical anecdotes or popularization literature. Rigorous attempts to address beauty in science are so scarce that I can name only two: McAllister's work (1996, 1998, 2005) and Theo Kuipers' article "Beauty, a Road to the Truth?" (2002).[1] McAllister (1996) compellingly documents that aesthetic evaluations of scientific theories are not only common practice, but also an influential factor in the progress of science. This allows him to develop a rationalistic model of scientific change which accounts for aesthetic evaluations and scientific revolutions. McAllister elaborates two theses: first, that the scientists' aesthetic preferences evolve driven by the aesthetic induction. Second, that scientific revolutions are aesthetic ruptures, that is, episodes in which the set of aesthetic criteria held by a scientific community is replaced by a different one. Crucial for McAllister's rationalistic project is to show that the scientist's aesthetic evaluations are not irrational. McAllister thus attempts to connect the scientists' aesthetic evaluations with the rational empirical evaluations they use to choose theories. In this context, McAllister discusses "two erroneous views of scientists' aesthetic judgments," which he calls *autonomism* and *reductionism* (McAllister 1996, Ch. 4). Autonomism "regards scientists' aesthetic and empirical evaluations as wholly distinct from and irreducible to one another, whereas reductionism views them as nothing but aspects of one another" (McAllister 1996, p. 61). McAllister rejects both views, and offers his alternative *inductive* connection: scientists increase their appreciation for properties recurrently appearing in empirically adequate theories. This is because they inductively project that when a new theory exhibits those properties, the theory will be empirically adequate (McAllister 1996 p. 77–79). The key element to give aesthetic

[1] The subject of beauty and aesthetics in science has been addressed by some authors, Paul Thagard (2005), for example, in the context of a rigorous study, but in general it is not addressed as the *central* subject.

evaluations and scientific revolutions a rational basis is the *aesthetic induction*, defined as follows:

> A community compiles its aesthetic canon at a certain date by attaching to each property a weighting proportional to the degree of empirical adequacy then attributed to the set of current and recent theories that have exhibited that property. The degree of empirical adequacy of a theory is, of course, judged by applying the community's empirical criteria for theory evaluation. I name this procedure the aesthetic induction (McAllister 1996, p. 78).

Now, in situations where scientists have to choose between empirically equivalent theories, they prefer theories bearing properties with the highest weighting within the canon (McAllister 1996, pp. 78–81). McAllister suggests imagining that scientists hold as many aesthetic criteria as there are aesthetic properties of theories. The collection of all those criteria constitutes their aesthetic canon. McAllister models an aesthetic canon as an exhaustive list of aesthetic properties of theories P along with a corresponding weighting W_P, as follows:

P, W_P
Q, W_Q
R, W_R
…

The quantity WP represents the intensity with which its associated property P is valued over other properties within the canon (McAllister 1996, pp. 34–35). McAllister gives this illustration of the aesthetic induction at work:

> A scientific community looks back over the recent history of a particular branch of science. It perceives that some theories, which are to a notable degree visualizing (rather than abstract) theories, have been empirically very successful, whereas others, which lend themselves to mechanistic analogies, have won little empirical success. Both visualization and tractability by mechanistic analogies are aesthetic properties of theories. In consequence of the empirical success of the visualizing theories, the property of visualization will obtain an increased weighting in the aesthetic canon for theory evaluation that the community will hereafter apply. By contrast, the property of being tractable by mechanistic analogies will receive a lowered weighting in the canon, in virtue of the scarce empirical success of recent theories that displayed this property (McAllister 1996, pp. 78–79)

According to McAllister, "[t]he aesthetic induction is an instance of inductive projection, since it amounts to consulting the properties of past good theories to determine which future theories should be expected to be good" (1996, p. 79). Moreover, the aesthetic induction induces a bias toward the properties of successful theories:

> By imagining the aesthetic induction in operation, we can infer how a community's set of aesthetic preferences among theories will evolve in particular circumstances. A theory that achieves significant empirical success will cause its community's aesthetic canon to be remodeled to a certain extent, in such a way, that the canon comes to attribute a greater weighting to that theory's

aesthetic properties. The canon will therefore acquire a bias in favor of any future theories that exhibit the aesthetic properties of current successful theories. In other words, by their empirical success, theories can predispose the community to choosing future theories with properties similar to their own (McAllister 1996, p. 79).

Now, the periods in which the aesthetic criteria evolve gradually are analogous to Kuhn's normal science periods. The episodes of aesthetic rupture, in which an aesthetic canon is relinquished, are scientific revolutions. McAllister documents these claims with a range of historical cases (McAllister 1996, Ch. 3, 5, 7, 8, 10 and 11). Now, McAllister's model of scientific change is beyond the scope of this paper; our main focus here is only on the mechanism of preference evolution.

1.1 McAllister's aesthetics

To account for the idea of beauty in science and to distinguish aesthetic from empirical criteria, McAllister endorses the following elementary aesthetic theory: 1) *Projectivism*: McAllister rejects objectivism, which is the view that beauty is an objective property of objects. Beauty is not interpreted as an objective property but as a value that observers project into objects. A value is something that is considered good, important or desirable. 2) *Aesthetic Properties Evoke Aesthetic Responses*: objects, including scientific theories, may possess intrinsic properties that evoke aesthetic responses in the observer and lead to project aesthetic value into those objects. These properties are the aesthetic properties. 3) *Beauty in Science*: A scientist is moved to project beauty into a theory when he holds to aesthetic criteria that attribute value to the properties of that theory (McAllister 1998, p. 30–34).

In this theory, making aesthetic evaluations depends on two factors: the objects bearing aesthetic properties and the values in the person observing the object. *Aesthetic criteria* are responsible for the attribution of beauty to objects that bear certain properties (McAllister 1996, p. 34). Different people hold to different aesthetic criteria. This explains why the same object evokes different aesthetic responses in different individuals.

1.2 Kuipers and the nature of aesthetic induction

Theo Kuipers (2002), endorsing McAllister's ideas and findings, further explores the aesthetic induction to formulate a theory of the relation between truth and beauty. Here I concentrate only on Kuipers' ideas on the aesthetic induction: he claims that a hypothetical variant of *mere-exposure effect* (MEE hereafter) can account for it. The MEE is "the fact that an increasing number of presentations of the same item tends to increase the aesthetic or, at least, affective appreciation of that item" (Kuipers 2002, p. 297). The MEE has "first a phase of monotone increasing aesthetic appreciation with the number of confrontations", followed by a second phase of decreasing appreciation (Kuipers 2002, p. 297). This feature is called the MME's U-shape. The switching point of the U-shape can be prompted or retarded depending on experimental conditions. Kuipers points out two experimental conditions that have not yet been studied: successive variation of the same stimulus; and introducing some kind of reinforcement. He conjectures that they might retard the U-shape switching point. Kuipers labels the MEE under these conditions *qualified mere-exposure effect*:

> McAllister's notion of 'aesthetic induction' can be seen as a reinforcement variant of the mere-exposure effect. More specifically, McAllister claims that aesthetic induction is triggered by empirical success, i.e., in psychological terms, empirical success functions as a kind of reinforcement. If the number of empirically successful theories with a certain nonempirical feature increases the aesthetic appreciation of that feature increases. Similarly, if increasingly many empirically successful revisions of a theory have a constant nonempirical feature, that feature becomes aesthetically more and more appreciated (Kuipers 2002, p. 299).

Kuipers also offers a formal analysis of the aesthetic induction, which sees the aesthetic induction as consisting in the co-occurrence of two mechanisms he labels *affective induction* and *cognitive meta-induction*. Affective induction is an inference-like process driven by the qualified mere-exposure effect. Cognitive meta-induction is an inference similar to inductive projection (although with an extra psychological component) and it is closer to a traditional cognitive mechanism of induction (Kuipers 2002, pp. 300–302).

2 Problems

McAllister's work is the first articulated model of beauty in science, therefore problems should be expected (see, for example, Davies 1998; Miller 2005). But here we are concerned only with problems with the aesthetic induction. I have identified two types of problems: explanatory anomalies and theoretical tensions.

2.1 Anomalies

The aesthetic induction cannot account for the patterns of evolution of what I call *historical constants* (especially, of *negative* historical constants). I elaborate: in the aesthetic induction, the track record of experiences with certain property determines the intensity of the preference for that property. The aesthetic induction does not differentiate between, for example, simplicity and being visualizing, or simplicity and its opposite, complexity. But in actuality, as we will see below, the aesthetic induction affects different properties differently. Let us first define historical contingencies and constants: properties like being abstract, being visualizing (in the sense of not being abstract, but rather offering a visualization of phenomena), or being tractable by mechanistic analogy, using McAllister's own examples, seem to evolve in great accord with the aesthetic induction: they have exhibited varying degrees of preference in different historical periods. How these properties fare historically in terms of preference is a contingent matter[2]. I label this type of properties *historical*

[2] As a matter of fact, from today's perspective, it is difficult to see how properties like visualizability or tractability by mechanistic analogy can be even considered as *aesthetic* qualities. This is precisely because the appreciation of such properties is determined by contingent historical contexts. Our contemporary context is one in which visualizability or tractability by mechanistic analogy seem simply deprived of any aesthetic character. This fact supports my labelling them *contingencies*.

contingencies. In contrast, properties such as harmony, symmetry or simplicity seem to consistently exhibit high degrees of preference throughout history. I label these properties *historical constants*.

McAllister's work shows that the aesthetic induction can account for the evolution of historical contingencies like being visualizing: this property increased its degree of preference as theories that relied upon visualizing phenomena accumulated a record of empirical success. But it is more difficult to account for the pattern of evolution of historical constants. Consider, for example, the properties of simplicity and complexity. Already in Ancient Greece, simple theories were preferred over complex ones. A similar situation can be found throughout history and among contemporary scientists: from *The Elements* of Euclid, to contemporary compilations of beautiful proofs like *Proofs From The Book* (Aigner and Ziegler 2004), simplicity is a highly valued feature. Prominent scientists like Ptolemy, Newton or, more contemporarily, Steven Weinberg. Philosophers of science are also aware of the importance of simplicity; as Donald Hillman remarks: "Principles of simplicity have been abundant, from Occam's Razor in fourteenth century philosophy all the way down to various twentieth-century attempts to interpret simplicity in its scientific connection" (Hillman 1962, p. 226).

Simplicity has enjoyed a stable degree of preference throughout history. McAllister does not seem to see this as problem. After all, the evolution of simplicity does not directly contradict the aesthetic induction, since simple theories do have a track record of empirical success to explain a high degree of preference. What is peculiar about simplicity is that, although preferences change constantly over time, the preference for simplicity seems to remain unchanged, even across scientific revolutions. McAllister, however, recognizes that there is something anomalous in properties like simplicity, since he devotes an entire chapter (McAllister 1996, Ch. 7) to discuss it. He concludes that simplicity plays a complex role involving empirical and non-empirical criteria for theory choice. Simplicity indeed plays a diversity of roles in scientific practice. The simplicity of a theory, an explanation or a mathematical formalism has epistemological, pragmatical and methodological advantages. For example, Popper connects a theory's simplicity with its falsifiability; simple statements are highly prized "because they tell us more; because their empirical content is greater; and because they are better testable" (Popper 2002, p. 128). Pragmatically and methodologically, a simple mathematical formulation, for instance, enables quicker and more accurate calculations, as well as further formal development. Some authors interpret simplicity as an indicator of *empirical* adequacy (Hillman 1962, pp. 225–226). The intricate nature of simplicity might somehow explain why the aesthetic induction seems to play a marginal role in its evolution. But if we focus on the instances of simplicity that have an aesthetic character, its evolution still poses questions. Now, simplicity may pose questions, but at least it is consistent with the aesthetic induction. Much more problematic are the patterns of evolution inconsistent with the aesthetic induction we will discuss below.

In McAllister's model, the aesthetic canon includes all possible, positive, negative or neutral, aesthetic properties (McAllister 1996, pp. 78–79). Thus, we can classify our aesthetic properties not only as historically contingent or constant, but also, as positive, negative or neutral. Let us consider simplicity's opposite: *complexity*, since the aesthetic induction does not differentiate properties there should be no problem.

The history of the preference for complexity is, of course, the mirror-image of the history of simplicity: the unappealing character of complexity remains unchanged throughout history; even across scientific revolutions. Now, a significant fact about the preferences for simplicity and complexity is that they are often overlooked to achieve empirical and epistemic success. This means that in the history of science there are not only simple theories with a track record of success, but also complicated theories with a track record of success.

Complexity in mathematics provides us with clear illustrations of this. For example, Greek mathematicians' predilection for simplicity had to be sacrificed to further advance the discipline (Kline 1990a, p. 175). A clearer illustration is provided by the different methods of proof regularly utilized by mathematicians. Simple methods, such as *reductio ad absurdum*[3], are among the most beloved methods ever since Euclid (Hardy 1992, p. 94). In contrast, complicated methods, despite their undeniable epistemic soundness were as unappealing to Greek mathematicians as they are to contemporary mathematicians. For example, G. H. Hardy declares that proofs by cases[4] may be sound methods of proof but ones "which a real mathematician tends to despise" (Hardy 1992, p. 114). A result proved by *reductio ad absurdum* is just as true as one proved by cases, but Mathematicians abhor proofs by cases. However, throughout history, prominent mathematicians like Cardano, Leibniz, Jacob and Johann Bernoulli, Euler, Lagrange, Legendre, or Gauss, attained relevant results by proofs by cases or by methods involving proving special cases (Kline 1990a and b). More recently proofs by cases have become conspicuous by achieving spectacular results and arising heated controversies: Appel and Haken's 1976 computer-assisted proof of the four-color theorem involved almost 2,000 cases, which arose aesthetic revulsion and posed questions about the validity of a proof that cannot be checked by a human being: "this particular "proof" is almost always what mathematicians think of when asked "What is an example of ugly mathematics?"" (Nahin 2011, p. 5). Proofs by cases have a very long history of success but mathematicians' preference for them has not increased. This contradicts the aesthetic induction directly. Moreover, the mathematician Gian-Carlo Rota (2005) even suggests that ugly proofs play a significant role in the development of mathematics, since they incentive seeking for alternative proofs.

And we can find complicated yet successful theories also in physics. The Standard Model is not necessarily regarded as a paradigm of beauty despite its great success:

> At present, there has been no experimental deviation from the Standard Model. Thus, it is perhaps the most successful theory ever proposed in the history of science. However, most physicists find the Standard Model unappealing because it is exceptionally ugly and asymmetrical. […] The reason why the Standard Model is so ugly is that it is obtained by gluing, by brute force, the current theories of the electromagnetic force, the weak force, and the strong force into one theory (Kaku and Thompson 1997, p. 75).

[3] In a proof by contradiction, or *reductio ad absurdum,* one assumes the negation of the statement to be proven and shows that it leads to a contradiction.

[4] In a proof by cases one divides the statement to be proven into a finite number of mutually exclusive cases, and then shows independently that in each case the statement holds.

There is more than enough evidence that complexity is a negative historical constant. And similar evidence can be easily found about properties like asymmetry or disharmony. The patterns of evolution of positive historical constants are consistent with the aesthetic induction; but negative constants contradict it. The aesthetic induction cannot account for negative historical because it treats all properties equally. Furthermore, another consequence of this is that the aesthetic induction allows implausible predictions. A good illustration of this is McAllister's application of his ideas to mathematics (McAllister 2005). McAllister argues that the aesthetic induction operates in mathematics in a fashion similar to how it operates in the empirical sciences:

> […] evidence that conceptions of mathematical beauty evolve under the influence of the aesthetic induction is provided by the gradual acceptance of new classes of numbers in mathematics, such as negative, irrational, and imaginary numbers. Each of these classes of numbers had to undergo a gradual process of acceptance: whereas initially each new class of numbers was regarded with aesthetic revulsion, in due course—as it demonstrated its empirical applicability in mathematical theorizing—it came to be attributed growing aesthetic merit (McAllister 2005, p. 29).

He also argues that the conception of acceptable proof has changed over time and draws our attention to the fact that, in recent decades, two new types of proofs have appeared: long proofs, such as Wiles' 108 page long proof of Fermat's last theorem and computer-assisted proofs. These types of proof challenge the classical conception of proof and McAllister speculates that they might even alter our conception of beautiful proof. McAllister proposes that the beauty of proofs depends on their acceptability; in the same fashion as the beauty of empirical theories depends on their empirical adequacy. Now, if mathematical beauty indeed evolves driven by the aesthetic induction, the preference for computer-assisted proofs must be driven by it as well:

> On the basis of the reception of computer-assisted proofs, I conjecture that the evolution of aesthetic criteria applied to mathematical proofs is also governed by the aesthetic induction (McAllister 2005, pp. 28–29).

Thus, in McAllister's view, the aversion to computer-assisted proofs is merely a contingency and their aesthetic might improve as they become acceptable. I believe that the historical evidence we have surveyed above does not support that conjecture. Complicated methods of proof have been *accepted* by mathematicians ever since Antiquity, but this did not result in an increase in the preference for those methods. Moreover, computer-assisted proofs are instances of proofs by cases. The history of this method of proof, against McAllister, seems to indicate that the aesthetic induction will not improve their aesthetic merit.

In general, negative historical constants constitute the clearest type of anomalies in the aesthetic induction due to the following features: 1) A long history of presence in science. 2) Their historical track record, due to the changing nature of science, must include some degree of success. 3) Contrary to what the aesthetic induction predicts, their degrees of preference remain small; otherwise they would not be *constants*.

2.2 Theoretical tensions

The aesthetic induction also has issues with its underlying assumptions. I have identified four of these problems: first, the aesthetic induction is not a genuine case of induction. Second, there is a confusion between the problem of beauty and the problem of the aesthetic. Third, there is an inconsistency regarding objectivism and projectivism. And fourth, McAllister's aesthetic theory plays no role in accounting for the evolution of aesthetic preferences.

2.2.1 Induction

McAllister sees the aesthetic induction as a special case of inductive projection. But a simple analysis reveals that that is not the case. Induction is a type of inference in which the features of an unobserved instance are predicted based on the features of a finite set of observed instances. More formally, induction is an inference in which we conclude a general or universal proposition from a set of finite instances of it. Its general form is:

Given that
a_1, a_2, a_3,…,a_n, are all *P*s that are also *Q*,
We conclude that
All *P*s are *Q*

Inductive projection is a variety of induction in which from a finite number of instances we predict the next instance. Its form is as follows:

1) a_1, a_2, a_3 ,…, an, are all *P*s that are also *Q*,
2) a_{n+1} is *P*,
We conclude that:
3) a_{n+1} is also *Q*

Now, if the aesthetic induction were a special case of projective induction, it would have the following form, which for convenience I label *Idealized Aesthetic Induction* (IAI):

IAI:

1) a_1, a_2, a_3,…, an are all *A* that are also *E*,
2) a_{n+1} is *A*,
3) a_{n+1} is also *E*.

Where: ai is a theory, *A* is an aesthetic property of scientific theories, and *E* is the property of being empirically adequate.

Now, IAI is adequate to model the *reason* why a scientist chooses a theory based on its aesthetic properties. However, it does not model McAllister's conception of the aesthetic induction: "a community attaches to each property of theories a degree of aesthetic value proportional to the degree of empirical success of the theories that have exhibited that property" (McAllister 1996, p. 4; see also, p. 78, cited in section 1). The aesthetic induction is the mechanism that determines the weightings *WA*. This is very different from the expressed by IAI.

McAllister seems to use the term ‘aesthetic induction’ ambiguously referring to the *mechanism* that determines the weightings W_A, and the *inference* that scientists use to justify their theory choices. Consider, for example, the case in which a scientist chooses a theory S over a competing theory T based not on empirical grounds but on the fact that S is symmetric. Symmetry is preferred over other properties because it possesses a higher weighting. In McAllister’s model, this degree of preference is the result of the fact that symmetric theories had been empirically adequate in the past. This process somehow resembles inductive projection. However, the act of choosing theory S is not an inductive procedure. Rather, it is merely the result of using the scientist’s aesthetic criteria, which is a simple deductive process of comparing degrees of preference and selecting the highest.

IAI expresses something completely different from the foregoing. IAI makes no reference to degrees of preference (W_P) or to how to determine such degrees. It expresses that since symmetric theories have been empirically adequate in the past, we can project that a new symmetric theory S will also be empirically adequate. The role of IAI is to *justify* that scientists act rationally when they base their theory choices on aesthetic criteria. What McAllister calls “the aesthetic induction” corresponds to a stage prior to the justification of the theory choice. In such stage, the degree of preference for certain property is determined by the track record of success of the theories that exhibited such property.

The aesthetic induction is not a special case of induction, but rather a mechanism with at least three discernible stages: a first stage that determines the degrees of preference; a second stage in which those degrees are employed to choose a theory; and a final stage in which inductive projection is used to rationally justify that choice. To clearly see the differences between IAI and McAllister’s ideas, I present a more accurate rendering of McAllister’s model. I label this model *Actual Aesthetic Induction* (AAI):

AAI:

AAI.1) An aesthetic canon is compiled by following this procedure: for every property *P* there is an associated weighting *WP* such that:

$$W_P = CD$$

Where:

W_P is the weighting associated to property *P*.
D is the degree of empirical adequacy as estimated by the history of success of *P*-bearing theories.
C is a constant that measures the proportionality between the degrees of empirical adequacy and the weightings W_P.

AAI.2) Given two equally empirically adequate competing theories T and S which exhibit the aesthetic properties *A* and *B* respectively, a scientist will choose T over S only if $W_A > W_B$.

AAI.3) The scientist makes that choice because he believes that IAI is correct, that is, he believes: **AAI.3.1)** a_1, a_2, a_3 ,…, an, are all *A* that are also *E*, **AAI.3.2)** a_{n+1} is *A*, and **AAI.3.3)** a_{n+1} is also *E*.

Where: a_i is a theory, *A* is an aesthetic property of scientific theories and *E* is the property of being empirically adequate.

2.2.2 Beauty vs. aesthetic

A central assumption in the idea of the aesthetic induction is that aesthetic evaluations in science are genuinely aesthetic[5]. This assumption should enable us to distinguish between empirical and aesthetic evaluations and, ultimately, to establish a *non-reductive* relation between them. McAllister, however, fails to distinguish between the problem of characterizing the *aesthetic* and the problem of elucidating the notion of *beauty*. These problems are clearly different. Understanding the nature of beauty is one of the central problems of aesthetics, but the problem of *the aesthetic* is much broader and relatively independent. The problem of *the aesthetic* has to do with identifying the mark of things like aesthetic judgements, aesthetic concepts, aesthetic values, and so on. The problem of the nature of beauty can be addressed by offering definitions like *being beautiful is to possess internal order* (Shaftesbury 1711). Addressing the problem of the aesthetic needs a completely different strategy. For example, Nick Zangwill (2010) starts by defining the notion of aesthetic judgement and then defines the remaining notions in terms of it: aesthetic properties are properties attributed by aesthetic judgements; aesthetic concepts are concepts used in aesthetic judgements; an aesthetic experience is what motivates the passing of an aesthetic judgement; and so on.

The confusion is evident when McAllister addresses aesthetic properties in two different occasions: the first time he defines them in terms of beauty, as properties that move the observer to project beauty (McAllister 1996, p. 32–33). In a second occasion, McAllister suggests two criteria for identifying aesthetic properties: the first criterion is that a property is aesthetic if it appears in a public aesthetic expression uttered by a scientist. The second criterion is that “if in virtue of possessing that property, a scientific theory is liable to strike beholders as having a high degree of aptness” (McAllister 1996, p. 37). This time, McAllister seems to be concerned with the relation between aesthetic properties and aesthetic responses, and with what makes a property aesthetic. Although these ways of addressing aesthetic properties do not contradict each other, McAllister utilizes a mixture of strategies. Now, the issue of characterizing aesthetic properties is a contentious issue and we should not expect a definitive answer in this context. But, for that very reason, a more *consistent* treatment of the problem is desirable.

2.2.3 Objectivism-projectivism inconsistency

McAllister’s aesthetic theory rejects objectivism and endorses projectivist. However, in the second criterion for identifying aesthetic properties, McAllister resorts to a non-projectivist criterion, since it relies on aptness. McAllister endorses projectivism as a way to avoid the metaphysical complications of objectivism. However, he seems to relax his position in crucial moments, like in his characterization of aesthetic properties (McAllister 1996, p. 37). Now, projectivism is not the only available way to

[5] Some authors (v. g. Davies 1998 and Miller 2005) challenge the very idea that the aesthetic properties of scientific theories are genuinely aesthetic. I believe that this challenge can be dismissed (see Montano 2010), but that discussion is beyond the scope of this paper.

avoid metaphysics. Kuipers, for example, prefers a naturalistic approach. We will exploit this below.

2.2.4 Theory and modelling

The aesthetic principles endorsed by McAllister play no role in shaping the aesthetic induction. The details of how the aesthetic induction operates are obtained by using historical evidence. This disconnection is worrying since the aesthetic induction intends to *connect* aesthetic with empirical evaluations. This is evident in McAlister's inherent tenet that the aesthetic terms used by scientists *literally* refer to genuine aesthetic properties. However, the function of the aesthetic induction, modelling the evolution of aesthetic preferences, does not require a literal interpretation of those aesthetic terms. The aesthetic induction itself does not involve things like affective responses, aesthetic pleasure or any of the characteristics usually attributed to aesthetic phenomena. It depends only on historical evidence. In this sense, a perfectly good model of the evolution of preferences can be obtained by attending to evidence without resorting to an aesthetic/empirical distinction (the only thing we need is a much weaker non-empirical/empirical distinction). McAllister's aesthetic theory is not really necessary for his aesthetic induction. McAllister, however, insists upon an aesthetic interpretation. For example, he attempts to show the existence of a mechanism of aesthetic induction in the arts[6] (McAllister 1996, Ch. 9). Even if aesthetic induction in the arts supports McAllister's ideas, that does not give his aesthetic theory a role in the aesthetic induction. A closer relationship between aesthetic theory and preference evolution modelling is desirable if a non-reductivist and genuinely aesthetic account of beauty in science is to be achieved. In that respect, Kuipers' naturalism is attractive. Unfortunately, since Kuipers endorses McAllister's basic ideas his approach suffers from the same problems and from its own issues.

2.3 Kuipers' problems

Kuipers connects the aesthetic induction with *affective* phenomena via the mere exposure effect (MEE), but he still endorses induction: future preferences depend on previous experiences with certain properties. However, induction is cognitive whereas affection is non-cognitive. Robert Zajonc, for example, sees MEE as evidence of the existence of the *emotional* memory, a memory system independent of the familiar system of declarative (cognitive) memory (Zajonc 1980, 1994, 2000). In contrast, the standard notion of induction interprets inductive inferences as cognitive phenomena, or at least as explicit conscious operations with certain formal characteristics. Kuipers' affective "induction" may be interpreted as non-cognitive, but then it is difficult to see it as genuine induction. Furthermore, Paul Thagard has pointed out that Kuipers' affective induction does not even possess the form of induction (Thagard 2005, p. 366). The aesthetic induction formulated in terms of affective phenomena cannot be seen as a case of genuine induction, either conceptually or

[6] He draws our attention to the case of iron, steel and concrete structures in architecture, which were introduced for practical reasons but gained aesthetic significance as they appeared recurrently in architectural designs.

formally. Despite its issues Kuipers' approach shows that empirical insights can improve our understanding of beauty in science. Embracing Kuipers' spirit, I will utilize empirical findings to amend the aesthetic induction.

3 Naturalizing the model

To formulate a more accurate and consistent model of the aesthetic induction, my strategy is to supplement historical evidence with findings in the study of affection. I thus endorse a naturalistic approach, and to do this the most urgent issue is to dispose of induction: I interpret the aesthetic induction as a *natural phenomenon* that should be modelled attending to their historical, empirical and formal features. Another urgent action is to revise the model's theoretical foundations, to do this I will employ a *naturalistic* aesthetic theory.

3.1 A naturalistic aesthetic theory

My aesthetic theory comprises the following assumptions:

1) I interpret *the aesthetic* (in the sense of 'the mark of the aesthetic') as a natural phenomenon. *The aesthetic* is a process of interaction between the subject and his natural and social environment.
2) This interaction is grounded on characteristic *affective* episodes that constitute the core of what is commonly known as aesthetic experience[7].
3) The predicate 'aesthetic' that qualifies notions like aesthetic judgement, aesthetic concept, aesthetic value, and so on, must be interpreted as indicating that the things that it qualifies (judgements, concepts, values, etc.) play an indispensable role in the development of the process of aesthetic interaction.
4) Terms such as 'beautiful', 'elegant', 'ugly', and so on, which appear in aesthetic evaluations, are *aesthetic terms*. Aesthetic terms play the role of elucidating, articulating and expressing the affective state of an individual engaged in appreciating an object (even a fictive or abstract object).
5) Aesthetic terms that qualify scientific theories must be taken at face value; scientists utilize aesthetic terms in the same manner as any other person.
6) Since aesthetic episodes are natural phenomena, the evolution of aesthetic preferences is influenced by three factors: first, by the history of the development of such phenomena. Second, by the interaction between the subject and his community. And third, by the inherent natural factors involved in the affective phenomena that ground aesthetic episodes. The description of the evolution of aesthetic preferences is not a theoretical matter, but an empirical one. Thus, in such description, historical and scientific evidence must be taken into account.

This theory avoids the theoretical tensions discussed above since the conception of the aesthetic is clearly distinguished from the use of the term 'beautiful'. The objectivism-projectivism divide is not relevant to the theory, since a process of aesthetic *interaction* involves objective as well as subjective

[7] For a detailed presentation of a naturalized approach to aesthetic experience see Montano (2010, Ch. 3).

phenomena. Finally, this naturalistic theory not only provides room for empirical input, but it relies on it. A more detailed discussion of a naturalistic aesthetic theory is beyond the scope of this article, but the details presented above should suffice to achieve our goals.

3.2 Naturalizing the aesthetic induction

In the context of my naturalistic aesthetic theory, the aesthetic induction is a form of *long-term* (hence history-dependent) interaction between the individual and his *social environment* and the patterns of evolution it induces are influenced by social as well as natural factors. McAllister's aesthetic induction models a great deal of the social factors, but the natural factors do not figure in the model. Kuipers' approach integrates some of the natural factors but he insists upon induction. Abandoning induction allows us to integrate more of the natural factors into the model. A wider range of empirical findings, such as the emotional memory, are now available to us.

3.2.1 Preference, affection and emotion

To model the evolution of aesthetic preferences in science we already have the historical evidence provided by McAllister's work. But our naturalistic approach must also consider the natural factors that influence those preferences. In the last decades, much progress has been done in the study of that subject. Preferences as basic as our predilection for sweetness, or our aversion to bitterness have been studied in detail. Several factors, including inherent biological factors, influence the formation of preferences. Robert Zajonc remarks:

> Preferences are formed by diverse processes. Some objects, by their inherent properties, induce automatic attraction or aversion. Sucrose is attractive virtually at birth, whereas bitter substances —quinine, for example—are universally aversive. Preferences may also be established by classical or operant conditioning […,] by virtue of imitation […, and] from conformity pressures. In economics, preference is regarded as the product of rational choice […] (Zajonc 2001, p. 224).

The particular kind of preferences in which we are interested here are those that are accompanied by an affective response, since those are the preferences involved in aesthetic evaluations. To address the influence of affection and emotion over the evolution of preferences one of the most useful findings, held by authors like Joseph LeDoux (1996), is that emotions are innate systems of response whose function is to promptly prepare an organism for coping with its environment. The experimental basis of this idea comes from sources like the study of fear in mammals. In responses of fear, an organism faces a potentially harmful stimulus. The stimulus triggers a process which includes the activation of two redundant neural pathways in the brain. The first pathway runs through a region in the brain known as the *amygdala*. The *amygdala* makes a rapid –twelve milliseconds in a rat– but crude assessment of the situation. This assessment triggers a further series of physical, psychological and physiological responses which prepare the organism for dealing with the imminent danger. Simultaneously, it is activated a second neural pathway which runs through the cerebral cortex where a slower –twice as long as the *amygdala* response– but more refined assessment of the situation is conducted. This refined assessment enhances or inhibits the responses triggered by the amygdala's rapid and crude assessment (LeDoux 1996, p. 163–165).

There are three elements of LeDoux's findings that are relevant to our purposes: first, emotions have a biological basis. Second, emotions have associated physiological responses. Third, emotions, in addition to a rapid non-cognitive component, have a *cognitive* one. Higher cognitive processes occur in the cortex. The cortical pathway in fear responses is thus a sort of cognitive "control" of the response (LeDoux 1996, pp. 264–290). The cognitive component of emotions is deeply associated with what I will call the *plasticity of affection and emotion*. The features of the mere-exposure effect are instances of affective plasticity: affective and emotional responses are inherently determined by biology and do not depend on a history of prior exposure of triggering stimuli. Exposure of stimuli, however, does modify affective responses. This occurs even in the "absurdly simple" (Zajonc 2001, p. 224) circumstance of mere repeated exposure of stimuli.

Instances of emotional plasticity are even more interesting. Emotions such as fear exhibit a wide range of adaptability: it is natural to be afraid of loud noises or an unknown dark environment. These fear responses are biologically conditioned. But there are also responses like fear of losing one's job, or fear of losing one's investments in the stock market. Such responses illustrate the adaptability, the plasticity of fear (Robinson 2005, pp. 72–74). Those 'cognitive' fears are the result of a process of gradual adaptation that involves the cortical pathways associated with the biologically determined response of fear (Robinson 2005, p. 73).

Now, according to McAllister and, especially, Kuipers, the history of experiences with certain property highly influences the evaluation of theories bearing that property. There are obvious similarities between this phenomenon and the plasticity of affective responses and it is reasonable to argue that affective plasticity is one of factors behind the patterns of evolution of preferences modelled by the aesthetic induction.

3.2.2 Constraints of affective plasticity

Although it can be argued that McAllister's and Kuipers' approaches manage to model the influence affective plasticity has over the evolution of preferences, the anomalies in their approaches remain unaccounted for. The good news is that since affective plasticity is one among the many factors that influence the formation of preferences, we have further insights to help us to refine our model.

Our innate preference for sweetness and aversion to bitterness show that some preferences are not formed by a history of experiences with stimuli. Emotion and affection are also innate; as their survival value depends on the fact that they are responses readily available to the organism, independently of its history of experiences. In this sense, some stimuli can be interpreted as possessing properties that elicit responses inherently, without the need of previous experiences. A way of incorporating this feature of affection into our model of evolution of preferences is to consider that historical constants might be associated with biologically determined affective responses. This interpretation allows us to account for the evolution of such properties in a more realistic manner without resorting to hypothesis such as the intricate nature of simplicity.

Now, affection and emotion characteristically involve physical and physiological changes which constraint them. If the inherent biological readiness of emotions is liable for the fact that they are independent of experiences with stimuli, and the cognitive control is liable for their plasticity, then the physical and physiological changes are liable for restricting that plasticity. In an emotional episode, the organism experiences changes in heart rate, in skin conductivity, in muscular blood flow; it also releases neurotransmitters, secretes hormones, and so on (Frijda 1986, p. 155). All these events occur in sequences that determine the development of the emotional episode. The secretion of hormones, for example, results in chemical changes in the organism. Those hormones and their associated chemical changes remain in the organism depending on physical and chemical factors and thus their effects can be felt long after the emotional episode has ceased. This is why in episodes of intense fear or anger the organism is unable to return to a relaxed state even if the stimulus that triggered the response has vanished (Frijda 1986, pp. 133–135).

Physical and chemical changes can occur only within certain parameters. Physiological changes in emotional episodes are constrained by factors such as the characteristics of chemical reactions or the way in which molecules are transported within the organism. This affects the way in which emotions develop. By the same token, the plasticity of emotions is constrained to remain within certain limits determined by the physical and physiological characteristics of emotional responses. When emotions undergo adaptations, those adaptations occur in a manner determined by the physiological parameters associated with the emotion. Furthermore, the different types of emotional response have different profiles of physiological arousal. These profiles manifest themselves even when the emotion is triggered not by a perceptual stimulus but by a cognitive input. This means that even if emotions such as fear are very plastic, their adaptation tends to remain within the range permitted by the profile of the emotion (Ax 1953; Frijda 1986; Levenson 1994; LeDoux 1996). Thus, the plasticity of emotions is inherently limited in two respects: the rate and range of adaptation. And since different emotions have different physical and physiological profiles and each organism possesses a particular biological constitution, the limits of plasticity vary depending on the type of emotion and the individual.

The constraints on plasticity must further shape our model of preference evolution. Recall the case of mathematics: mathematicians' aversion to complicated methods of proof does not change throughout history despite the fact that the methods are sound, accepted, and have a long history of success. This pattern of evolution contradicts the aesthetic induction, but it is consistent with the constraints on plasticity: affective responses can adapt only within certain range and at a certain rates depending on the physiological profile of the response. The fact that certain aversion remains unchanged should be seen as evidence that the type of affective response associated to such aversion has a limited degree of plasticity or that it has reached the limit of such plasticity. A model of the evolution of preferences that incorporates these inherent characteristics of affection should be able to account for the anomalies in the original model. I now introduce that model.

4 Conceptualizing preference evolution

In section 2.2.1, we saw that the aesthetic induction is not really induction. Our analysis also made evident that a more formal approach is less prone to confusion. To formulate the new model I will use a similar formal[8] approach and, later on, utilize my rendering of McAllister's model as a template for the new model. Now, in order to incorporate the features of affection and emotion discussed above, we need to introduce some concepts which will allow us to model those features.

4.1 The aesthetic canon as a system

McAllister's interpretation of an aesthetic canon as an exhaustive list of aesthetic criteria, that is, pairs of properties *P* and weightings *WP*, is very convenient since any evolution in the canon can be represented simply as changes in the weightings. But listing aesthetic criteria is rather informal. A more convenient way of dealing with a collection of criteria is by using set theoretical notions, as we can resort to all kinds of useful tools. For example, the notion of *system* is particularly useful when we have sets that change over time. A system is a set of elements (often called 'components') and relations that allow us to model complex behaviours. In order to take advantage of the concepts available in systems theory, I interpret an aesthetic canon as a *system* of aesthetic criteria. I define an aesthetic canon, *Acanon*, as follows:

$$Acanon = \{(P, W_P(t))\}$$

where: *P* is an aesthetic property of theories, and $W_P(t)$ the degree of preference for *P* at a certain time *t*.

This interpretation allows us to describe how an aesthetic canon evolves simply by describing how the weightings change. Borrowing further ideas from systems theory, we can see the process of determining the weightings as a description of the *dynamics* of the system. In this respect, the notion of *evolution rule* is relevant. The *evolution rule* of a system is the rule that describes what future states of the system result from its current state. For example, the first phase of my rendering of McAllister's model in section 2.2.1, which sets the weightings W_P, can be seen as a description of the dynamics of McAllister's aesthetic canon. And its evolution rule, as rendered in AAI.1, in section 2.2.1, is: $W_P = CD$.

Unlike McAllister's our naturalistic approach must incorporate the effects of affection's inherent biological readiness and affective plasticity. Thus, we must consider appropriate parameters for those factors. I introduce the notions of *critical adequacy* and of *robustness of critical adequacy* to accomplish that.

[8] It must be noted that Kuipers (2002) offers a formal analysis of the aesthetic induction as well, but since Kuipers' model suffers from the same problems as McAllister's, I pursue a different direction here.

4.2 Critical adequacy

I define critical adequacy as follows:

Critical Adequacy:

An object O is critically adequate if and only if there is a property *P* of O that warrants that an average person with the appropriate experience will pass a positive aesthetic judgement about O.

Critical adequacy embodies the fact that the presence of pleasing (or displeasing) properties motivates the eliciting of judgements. The person's *experience* involved in the definition may include, in the scientific context, considerations such as *empirical adequacy*. The inclusion of a person's experience warrants that critical adequacy can play a role analogous to the role played by empirical adequacy in McAllister's model.

Now, the influence of a property upon the aesthetic canon is represented by its weighting. In order to incorporate the influence of aesthetic adequacy into our evolution rule we must represent it as a *parameter* in an evolution rule. A notion of critical adequacy that admits degrees is more suitable for this purpose. Thus, consider the following definition:

Degree of Critical Adequacy:

An object O has a high degree of critical adequacy if and only if there is a property *P* of O whose presence makes very probable that an average person with the appropriate experience will pass a positive aesthetic judgement about O.

The degree of critical adequacy embodies the intensity with which an object with certain properties fits the taste of a person or community. Affective plasticity allows an aesthetic canon to evolve, and it explains that the aesthetic canon's dynamics is linked to the history of experiences with certain properties. The biological constitution of affective phenomena explains the fact that there are objects and properties capable of invoking affective responses regardless of any previous experience with such objects or properties. The notion of critical adequacy models this characteristic. The degree of critical adequacy can be used to model the dynamics of an aesthetic canon in a manner analogous to McAllister's evolution rule.

Now, the constraints on affective plasticity are still absent from our model. To address this issue, I introduce the notion of *robustness of critical adequacy*.

4.3 Robustness

We have seen that the degrees of preference for properties like simplicity or complexity tend to remain unchanged over extended periods of time. The fact that preferences are greatly influenced by our biological constitution and by the constraints on affective plasticity can account for this pattern of evolution; or, at least, for the fact that preferences resist arbitrary or unconstrained changes. This characteristic resembles what in systems theory is known as the *robustness of a system*, which is the system's ability to remain unchanged or to sustain little change despite the perturbations induced by the environment. I borrow the idea of robustness to refine the description of the dynamics of an aesthetic canon. It must be pointed out that although I have offered a possible empirical explanation of robustness, the notion formulated below can be seen as having mostly a descriptive character. It allows us to model the pattern of evolution of historical constants without committing to a specific explanation of it. Consider thus the following definition:

Robustness of Critical Adequacy:

The critical adequacy of a property *P* of an object O is robust if and only if *P* is able to motivate the same affective response despite changes in the history of experiences with *P*.

As before, a definition in terms of degrees is better suited to be incorporated as a parameter into an evolution rule.

Degree of Robustness of Critical Adequacy:

The critical adequacy of a property *P* of an object O is robust in a high degree if and only if in most cases *P* is able to motivate the same affective response despite changes in the history of experiences with *P*.

What this definition tells us is that properties with robust critical adequacy will tend to maintain their degree of critical adequacy despite the fact that a history of experiences with such properties builds up over time. This is precisely the pattern of evolution of historical constants, which indicates that those properties possess a high degree of robustness. The degree of robustness introduces differences among properties regarding their patterns of evolution. Properties with a low degree of robustness change depending on the contingencies that affect the aesthetic canon, whereas properties with high degree of robustness remain more or less unchanged.

4.4 Dynamics of the new model

With the concepts introduced above, we can now model the dynamics of an aesthetic canon as follows:

Naturalistic Dynamics of an Aesthetic Canon:

The evolution of an aesthetic canon is governed by the following mechanism: A community compiles its aesthetic canon at a certain time *t* by attaching to each aesthetic property an associated weighting according to the following function, which I call *Naturalistic Evolution Rule* (NER):

Naturalistic Evolution Rule (NER):

$$W_P(t) = (1 - R_P)CA_P + R_P W_P(\mathrm{t} - 1)$$

Where:

$W_P(t)$ is the weighting of *P* at a certain time t, resulting from the evolution of the aesthetic canon.

$W_P(t\text{-}1)$ is the original weighting of property P at a prior time $t\text{-}1$, before the evolution of the aesthetic canon.
A_P:[9] is the degree of critical adequacy of P, whose range is the closed unit interval [0, 1].
R_P is the degree of robustness of P, whose range is [0, 1].
C is a constant that measures the ratio between the weightings and the degrees of critical adequacy.

This function has the desirable characteristic that if the robustness R_P is very low, the function is similar to McAllister's evolution rule. But if the robustness is high, the function mimics the tendency of certain preferences to remain constant over time. Consider the case in which robustness is ideally low, with R_P=0. The function reduces to $W_P(t)$=CAP. That is, the weighting associated to P is proportional to P's critical adequacy, which is a generalization of McAllister's evolution rule W_P=CA.

Consider now the case in which robustness is ideally high, with R_P=1. The function reduces to $W_P(t)$=$W_P(t\text{-}1)$. That is, the weighting remains unchanged, which is the pattern of evolution of an ideal historical constant. Of course, for non-ideal cases, the function yields values that reflect the effect of the various factors involved: the proportionality to critical adequacy and the effect of the robustness of each property. Now, NER is merely an illustration of a suitable evolution rule and it does not intend to be a factual model. It only intends to show that the "inductive" aspects, modelled by the proportionality $W_P(t)$=CA_P, and the "affective" aspects, modelled by the robustness $W_P(t)$=$W_P(t\text{-}1)$, can be integrated in a consistent manner.

NER can account for the same cases as McAllister's rule, since NER has $W_P(t)$=CA_P as a special case. The function can also account for McAllister's anomalies in a natural fashion. For example, the pattern of evolution of a negative historical constant can be interpreted as evidence that such property possesses a low degree of critical adequacy and a high degree of robustness. The naturalistic evolution rule yields more accurate descriptions than the original aesthetic induction. Thus, the model of evolution proposed here is more general than McAllister's not only in formal terms, but also in the sense that it covers its original as well as its anomalous cases.

5 The new model: constrained aesthetic induction

I will use my rendering of McAllister's model of the role of aesthetic evaluations in science (section 2.2.1) as a template for the new model. The model thus consists of three stages. The first stage describes the dynamics of the aesthetic canon. The second describes how a theory choice is conducted. The third

[9] Strictly speaking, we should write $A_P(t)$, for an aesthetic canon changes over time and the degree of critical adequacy changes with it. However, an aesthetic canon changes at a much slower rate than the individual degrees of preference; for the sake of simplicity the slow change in critical adequacy is neglected and the parameter treated as a constant.

justifies that choice. I label the new model *Constrained Aesthetic Induction* (CAI) and express it as follows:

Constrained Aesthetic Induction (CAI):

CAI is a natural process that occurs in the context of aesthetic episodes. Aesthetic episodes are natural processes of interaction between subjects and their natural and social environment. CAI unfolds through stages CAI.1 to CAI.3.

CAI.1) A community compiles its aesthetic canon, $Acanon=\{(P, W_P(t))\}$, at certain time t by associating to every aesthetic property P a weighting determined by the Naturalistic Evolution Rule (NER).

CAI.2) Given two equally empirically adequate competing theories T and S, which exhibit the aesthetic properties E and F respectively, a scientist will choose T over S only if $W_E(\mathrm{t}) > W_F(\mathrm{t})$.

CAI.3) The scientist makes that choice because he holds (perhaps unconsciously) that: **CAI3.1)** a1, a2, a3,…, an, are all P that are also Q; **CAI.3.2)** an +1 is P; and **CAI.3.3)** an +1 is also Q. Where ai is a theory, P is an aesthetic property of scientific theories, and Q is the property of being empirically adequate.

The label aesthetic *induction* is not completely accurate to name the new model since neither the evolution rule nor the model as a whole are proper instances of induction. Inductive projection is involved in the justification phase CAI.3, but its role is purely *epistemic*, not aesthetic. Although the term 'induction' in the new model of 'aesthetic induction' may be a little inaccurate, the model itself is a more accurate depiction of aesthetic evaluations in science, and it allows us to dispose of the problems with the original model.

5.1 Problems addressed

Addressing the problems with the original model is now simple. First, the anomalies: Since the original aesthetic induction is a special case of CAI, the results that can be obtained by using the original aesthetic induction can also be obtained by using CAI. We only need to assume a low degree of robustness in the aesthetic canon. This assumption, however, is not an accurate depiction of what occurs in actuality, as the existence of historical constants shows. For example, the pattern of evolution of simplicity is evidence that simplicity possesses a high degree of critical adequacy and a high degree of robustness. Similarly, the pattern of evolution of complexity is evidence that complexity possesses a low degree of critical adequacy and a high degree of robustness. In general, historical constants can be modelled as properties with a high degree of robustness, and historical contingencies as properties with low degrees of robustness. Historical constants are not anomalous in the new model.

The theoretical problems of the original model can also be addressed. The problems were: first, the aesthetic induction is not induction. Second, a confusion between beauty and the aesthetic. Third, an inconsistent projectivist position. And fourth, a faint link between theory and modelling. The first problem is not an issue since the new model is not based on inductive projection. The second problem is not an issue either: the new model is based on a naturalistic theory which differentiates beauty from the aesthetic: the aesthetic is interpreted in functional terms, whereas beauty is interpreted as an aesthetic term that articulates aesthetic experiences. Since aesthetic episodes are complex processes of interaction between the subject and the environment, the objectivism/projectivism distinction does not play a significant role. Finally, a naturalistic theory offers room for empirical description in a consistent way: the findings of empirical science are incorporated into the new model as parameters in the evolution rule. Moreover, since the new model is clearly not an instance of induction, there is no need to address issues such as the cognitive character of induction.

5.2 Differences

I must point out some significant differences between McAllister's model and the Constrained Aesthetic Induction. Although CAI can account for the same phenomena as McAllister's model, its role in a rationalist depiction of science is not quite the same. Note that the stages CAI.1 and CAI.3 in the new model are not as strongly linked as the stages AAI.1 and AAI.3 in the original model. In AAI, empirical adequacy plays a central role in both AAI.1 and AAI.3. In AAI.1, it plays the role of driving the evolution of the aesthetic canon. In AAI.3, it plays the role of justifying the use of aesthetic evaluations. These roles warrant the rationality of aesthetic evaluations, as McAllister intended. However, in the new model the link between the evolution of aesthetic preferences and the justification of their usage is less tight: empirical adequacy appears in CAI.3, but not in CAI.1. In the original model, empirical adequacy induces change in the scientists' aesthetic preferences. This means that theory choices made using such preferences are not merely subjective choices, but rather the result of the subtle influence of empirical criteria. Since subjective factors have been deflated in this depiction of theory choice, this choice is as rational as a choice based on empirical criteria. In the new model, critical adequacy also induces changes in the preferences. However, since critical adequacy is not so strongly linked to empirical criteria, the rationality of theory choice as depicted by the new model cannot be so firmly guaranteed. CAI might have an argument for the rationality of theory choice analogous to McAllister's, if two conditions were satisfied: first, in order to make the link between critical adequacy and empirical criteria stronger, it is required that the experience of the individual consists mostly of episodes of observing properties of empirically adequate scientific theories, since an individual under those circumstances will probably develop aesthetic criteria very similar to the aesthetic criteria depicted by McAllister. Now, even if this condition were the case, our model would not be analogous to McAllister's, since our model considers not only the effect of the change-inducing critical adequacy but also the effect of the change-inhibiting robustness. Thus, as a second condition, it is required that all properties are non-robust historical contingencies. Unfortunately, these two conditions are very unrealistic. Thus, in the new model, an argument for the rationality of aesthetic evaluations cannot take the same shape as McAllister's.

Now, accounting for the rationality of aesthetic evaluations is beyond the scope of this article. However, we can anticipate that any such account will be more complicated than a mere inductive relation to empirical adequacy, since, as we have seen, induction is insufficient to render an accurate description of the actual evolution of preferences. This, however, is not necessarily a drawback in the new model, since in recent years the study of the relation between affection and cognition has challenged their traditional divide (Damasio 1994; Ekman 1994; Robinson 2005). A defence of the rationality of aesthetic evaluations in science should certainly pay attention to such developments. The fact that the model proposed here does not assume a simple relation between affection and rationality is thus consistent with the results of current science.

6 Conclusion

We have seen that, by establishing an inductive relation between aesthetic and empirical evaluations, McAllister reconciles the existence of aesthetic judgements and revolutions in science with a rationalist depiction of it. We have also seen that Kuipers naturalized the aesthetic induction to investigate the relation between beauty and truth. I pointed out some issues in their models: historical constants as explanatory anomalies, and four problems of theoretical nature. Following McAllister's usage of historical evidence and Kuipers' naturalistic interpretation, I formulated a naturalistic model of the evolution of aesthetic canons that does not suffer from anomalies or theoretical tensions. The new model, Constrained Aesthetic Induction, provides a more consistent theoretical framework to understand beauty in science. It also constitutes an improvement in the scope and accuracy of the model's accounts, since it covers anomalous cases. Under ideal conditions, the original aesthetic induction can be seen as a special case of the new model.

The model introduced here is more accurate and internally consistent than McAllister's and Kuipers'. However, the consequences of my proposal for McAllister's model of scientific change and Kuipers' project do not seem to be positive at first sight. Rather, the new model constitutes a way of inviting the findings and ideas of current scientific research into the debate on scientific rationality and scientific truth. Exploring the role of the new model in issues such as the relation between beauty and scientific change, the relation between beauty and truth, scientific revolutions, or the continuity of science is a task that must be conducted in future works.

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