Scientific Progress and Aesthetic Values

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Milena Ivanova

University of Cambridge

1. Introduction

Aesthetic values have featured in scientific practice for centuries, shaping what theories and experiments are pursued, what explanations are considered satisfactory and whether theories are trusted. How do such values enter in the different levels of scientific practice and should they influence our epistemic attitudes? In this chapter I explore these questions and how throughout scientific progress the questions we ask about the role of aesthetic values might change. I start this chapter with an overview of the traditional philosophical distinction between context of discovery and context of justification, showing how aesthetic values were taken to be relevant to scientific discovery and not scientific evaluation, which was regarded value-free. I then proceed with an exploration of different levels of scientific activities, from designing experiments and reconstructing fossils to evaluating data. In this discussion we will see that the traditional distinction between context of discovery and justification seems to break down, as aesthetic values shape all levels of scientific activity. I then turn our attention to the epistemological question: can beauty play an epistemic role, is it to be trusted, or is it a suspect value that might bias scientific inquiry? I explore how we could justify the epistemic import of aesthetic values and present some concerns as well. In the last section I ask whether we should expect the questions surrounding aesthetic values in scientific practice to change with scientific progress, as we enter the era of post-empirical physics, big data science, and make more and more discoveries using AI.

1. Discovery and Justification

Stories of scientific discovery are filled with intriguing personal reflections of sudden illuminations, random and chaotic processes and personal guiding values. It is no surprise that for so long the philosophical approach to discovery was one of pure mystery; romanticist approaches to creativity emphasise the role of genius and mysticism surrounding the discovery process, and scientists in their turn described their discoveries dressed in inspirationalist cloaks. From Keluke’s dream to Poincaré’s stroll, discoveries in science and mathematics have been usually presented to us without reference to the context within which the problematisation happens, without much discussion of the community effort and ground work required for the work to take place, and much emphasis has traditionally been given to the sudden moment of illumination without reflection on what happens before and after the light bulb moment.

Personal values have often been at the forefront of the stories told about discoveries. Take for instance Poincaré’s account of creativity, which he develops in his chapter ‘Mathematical Discovery’ from *Science and Method*. Similarly to inspirationalism and the combinational account of creativity, Poincaré takes creativity to be the identification of unsuspected relations among known facts. But what is rather original in his account is the emphasis on the aesthetic sensibility. For Poincaré the creative process takes several stages: preparation, incubation, insight and revision. During preparation the subject consciously studies the problem at hand, while in incubation the mind freely explores possibilities without being conscious or constrained, then the ‘the unconscious machine’ comes up with ‘sudden illuminations’. Fortunately Poincaré tells us a little more about what happens next, as discovery is not just that one moment of illumination, which would have problematic repercussions for our credit attribution practises, given that it is an unconscious process. He tells us that the sudden illumination is followed by a critical conscious reflection in which the produced ideas are assessed, but this assessment is delivered by the scientist’s aesthetic sensibility, which acts as a “delicate sieve”, selecting the theories or proofs that best suit our aesthetic requirements.

Poincaré made discovery a little less mysterious and random compared to traditional inspirationalist accounts[[1]](#footnote-1), by giving it clearly defined stages, and opened the door to more productive explorations of scientific creativity. It nevertheless continues to place a central role to the aesthetic sensibility, implying that our aesthetic values shape what ideas we come up with. It is no surprise, then, that for so many decades philosophers of science refused to engage systematically with discovery. Hans Reichenbach (1938) drew a sharp distinction between context of discovery and context of justification, which was for decades adopted by the logical positivist school and also informed Karl Popper’s (1963) views on the scientific method. The idea behind this distinction is that aesthetic values are deemed psychological and subjective, and while they may be operating in the context of discovery, they have no place in our theory of knowledge. For Reichenbach, in constructing our theory of knowledge we should focus only on how our evidence relates to our hypotheses and ignore subjective or psychological factors that are operating in the discovery context. As he argues, “It would be a vain attempt to construct a theory of knowledge which is at the same time logically complete and in strict correspondence with the psychological process of thought” (1938, 5). Thus, from the time of the Vienna Circle up to even recent literature, aesthetic considerations were not the focus of systematic philosophical attention. If their presence in scientific practice was acknowledged, they were only given relevance to the context of discovery, rendering them not part of our rational acquisition of knowledge.

More recent reflections on scientific practice, however, have called into question the sharp delineation between the contexts of discovery and justification. It seems that value is pervasive in all levels of scientific theorising, and even selecting, processing and shaping the nature of the evidence is not without the involvement of value. From feminist critiques of science, exposing the heavy gender bias operating in how the evidence is selected and interpreted (Mann (2020), Martin (1991), Criado-Perez (2019)), to showing the operation of value in the selection and interpretation of theories (Duhem (1954), Kuhn (1962)), it seems like values are everywhere in the practice of science and the meaning of our observations and experimental results are not immune to our values. Whether this is bad news, a highly problematic aspect of science that needs to be amended for, or simply a fact about how we as agents operate in this world and shape our enquiry, has been disputed. For those who follow in the logical positivists’ path, science should be value-free in order to deliver the epistemic goods we aim for: objective knowledge about the world. On the other hand, philosophers such as Helen Longino (1980) have argued that values do not threaten the objectivity of science, but simply shift our understanding of objectivity not as an aspect of individual agents but of communities. Longino and Philip Kitcher (1990) have argued that the values operating in science need to reflect those of the communities that science serves, making values subject to critical democratic evaluation[[2]](#footnote-2).

In addition to the dissolution of the context of discovery and justification, certain philosophical developments in philosophy of science over the last decades have opened the door to studying the relationship between art and science. The popularity of the semantic approach to scientific theories put at the centre of attention the notion of representation, which led philosophers of science to draw analogies between scientific models and artworks as representational vehicles (van Fraassen (2008), Frigg and Hunter (2010)). Additional momentum to the interaction between philosophy of science and aesthetics was given by Bueno, et.al. (2017), and Ivanova and French (2020), opening further questions for investigation, including what aesthetic responses are elicited by scientific products, how aesthetic values shape our understanding, pictorial and other forms of representation and their aesthetic values, and the aesthetic nature of thought experiments. Catherine Elgin’s (1991) work, which compares literary works to thought experiments, has been instrumental in drawing connections between art and science, by showing how our understanding can be advanced through notions such as exemplification. We will return to the normative question whether aesthetic values undermine epistemic goals in the later sections of this chapter. For now, let us have a look at how aesthetic considerations shape scientific practice.

1. How aesthetic values shape scientific practice

Aesthetic values seem to feature rather prominently in all types of scientific activities and we can identify at least three levels of scientific practice at which we can find aesthetic judgements at play. First, the subject of our investigations, nature herself, is often regarded to afford aesthetic experiences, to be beautiful. From sunsets and beehive honeycombs, to rainbows and snowflakes, nature is regularly regarded as aesthetically pleasing, generating in us feelings of awe and wonder[[3]](#footnote-3). Second, the very products of scientific activities are also aesthetically appraised. The images scientists produce are often the subject of aesthetic appreciation, from pictures of oscillating particles, to Leonardo da Vinci’s careful depiction of the human body, to Robert Hooke’s drawings of the flee, scientific images have for centuries been compared to, or considered to be, artworks and claimed to afford aesthetic experiences in the viewer. Likewise, scientific models like the double helix structure of DNA molecules or the different models of the atom, mathematical proofs like Euclid’s Elements, experiments like Rutherford’s explorations of uranium radiation, and many scientific theories, from Newton’s and Einstein’s theories of gravity, to Darwin’s theory of evolution, the standard model in particle physics and string theory, all are claimed to be aesthetically valuable, beautiful, elegant and simple, and to elicit in us aesthetic responses (Ivanova (2017a)). Last, the very process by which scientists arrive at a product, whether constructing a proof or an experiment or arriving at a theory, can be subject to aesthetic judgements. The French physicist Pierre Duhem argued that:

[I]t is impossible to follow the march of one of the great theories of physics, to see it unroll majestically its regular deductions starting from initial hypotheses, to see its consequences represent a multitude of experimental laws down to the small detail, without being charmed by the beauty of such a construction, without feeling keenly that such a creation of the human mind is truly a work of art (Duhem 1954, 24).

Ernest Rutherford similarly reflects that theories can be seen as artistic productions: “a strong claim can be made that the process of scientific discovery may be regarded as a form of art. […] A well constructed theory is in some respects undoubtedly an artistic production” (quoted in McAllister 1996, 14). In the context of designing and performing an experiment, scientists are also very often compared to artists. Reflecting on the Michelson-Morley experiment, which aimed to detect ether drift, Albert Einstein remarked that Michelson was “the Artist in Science”, who derived joy from “the beauty of the experiment itself, and the elegance of the method employed” (quoted in Holton 1969, 157). The comparisons between scientific and artistic production can be traced back to the natural philosophers, during a time where generating feelings of amusement was one of the goals of the experimenter and experimental practice was often seen as a public spectacle (Ivanova (2021b), Parsons and Reuger (2000), Wragge-Morley, A. (2020)).

Let us explore some specific examples that shed light on how aesthetic values operate in the different levels of scientific practice. Caitlin Wiley (2015), and more recently Derek Turner (2019) and Adrian Currie (2020), have offered an illuminating discussion of how aesthetic factors function in the preparation of fossils in palaeontology. Wiley observed that when palaeontologists reconstruct a specimen, they employ their knowledge as well as aesthetic sensibility and enhance the aesthetic features of the specimen. This means that our aesthetic values have already entered the scientific activities before we have even started theorising, in the very preparation of the evidence we have. Glenn Parsons (2012) has also reflected on how aesthetic factors feature in chemistry, where it is not only that molecules are found to display aesthetic value, by displaying certain formal properties such as symmetry and elegance, but the very process of synthesis employed in producing new molecules is a source of aesthetic appreciation (2012, 578). When it comes to medicine, Chiara Ambrosio and Brendan Clarke (2018) have discussed how visual aesthetic factors have influenced studies in anatomy. Alexander Wraggle-Morley (2020) has further discussed how drawings of specimen by natural philosophers, such as Robert Hooke, embody aesthetic qualities, showing that the aim of the natural philosophers was not simply to depict the specimen, but to enhance nature’s aesthetic qualities and provoke an aesthetic response in the viewer.

Aesthetic considerations are also part and parcel of designing experiments. Scientists care for the creative process behind a well-designed experiment, praise a good experiment for its beauty and its designers for their creativity and ingenuity (Ivanova (2021b), Parsons and Reuger (2000)). And interestingly, even the reception of an experiment can be subject to aesthetic values. Experimental results are often evaluated on their beauty, regarding how clear they are. For instance, the famous Meselson-Stahl experiment in molecular biology, which confirmed the method by which DNA replicates, has not only been regarded as beautiful because of its design but also because of the clear and significant results it produced (Ivanova 2021a,b). And even thought experiments have received aesthetic praise for their elegance and simplicity, with Brown (2004) arguing that simplicity and original set-up makes Galileo’s thought experiment on falling bodies the most beautiful thought experiment in science.

One could claim that the above-mentioned activities and practices are all part of the context of discovery; ultimately evidence settles which hypotheses or theories withstand testing. We have already seen that scientific practice does not seem to allow us to make this distinction so clearly, and the extraction and evaluation of data is subject to values too, but it is worth exploring next how even our epistemic stance towards a theory can be affected by aesthetic values. Below I explore how scientists use beauty to justify their belief in scientific theories. Before I proceed, let me just mention that beauty can be understood as an irreducible aesthetic quality, and some scientists have certainly taken this stance, but in the discussion below it will become clear that often scientists take a reductionist understanding of beauty, analysing it in terms of aesthetic values such as elegance, simplicity, symmetry etc.

1. Beauty: systematic bias or guide to the truth?

Beauty is often seen as a motivator in scientific enquiry, but is also given significant epistemic weight by being regarded as an indicator of a theory’s truth. When it comes to its motivational role, scientists have claimed that they study nature in order to find the beauty within it. The French mathematician and scientist Henri Poincaré was instrumental in the development of this idea, that beyond the practical benefits of scientific progress, scientists are invested in studying the world because this activity delivers an aesthetic pleasure. Uncovering nature’s beauty, Poincaré argues, is what motivates scientists’ work. The beauty scientific practice uncovers is not one that is easily perceivable with our senses, he argues, but rather is uncovered by our intellect’s engagement with nature shaped by our understanding. In his own words:

"[t]he scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful […] I am not speaking, of course, of the beauty which strikes the senses, of the beauty of qualities and appearances. I am far from despising this, but it has nothing to do with science. What I mean is that more intimate beauty which comes from the harmonious order of its parts, and which pure intelligence can grasp” (Poincaré 2001, p. 368). The Nobel laureate Subrahmanyan Chandrasekhar, who dedicated much of his time thinking about the role of beauty in science, claims that scientists and artists ultimately have the same aims and that is to discover beauty in all its forms (Chandrasekhar 1987, p.52).

Being a motivator is one thing, but it hardly tells us that beauty can play a role outside of the context of discovery. However, in addition to being a motivator, beauty is often also seen as a pragmatic element in theory development as well as in theory evaluation. It is argued that it is convenient for us to develop theories that satisfy our aesthetic requirements and if we need to make choices between hypotheses that are equally supported by the evidence, it is most convenient for us to choose simplicity over complexity, beauty over ugliness. As the Austrian physicist Ernst Mach (1984) argues, we should always aim to explain the phenomena in the most conceptually economical manner, because simple theories are easier to use. He argues that science should be seen as an economical description of our observations, with simplicity being a guiding principle in the construction and evaluation of scientific hypotheses. In a similar manner, Poincaré argues that there is a relationship between utility and simplicity, in that a simpler theory is easier to use, making simplicity a regulative principle in the construction and choice of theories. According to him, “care for the beautiful leads us to the same selection [of theories] as care for the useful” and an economical theory “is a source of beauty as well as a practical advantage” (Poincaré 2001, 369). In the more recent literature on scientific realism Bas van Fraassen has also acknowledged the need to appeal to non-empirical factors in scientific practice. However, these aesthetic considerations are regarded as purely “human concerns, a function of our interests and pleasures, which make some theories more valuable or appealing to us than others. These values provide reasons for using a theory but cannot rationally guide our epistemic attitudes and decisions” (1980, 87). The aesthetic values are thus informing our activities, but should not guide our beliefs in the truth of a theory.

Contrary to this empiricist take on the role of aesthetic factors in science, many scientists take beauty to do much more than just act as a heuristic tool for convenience; they believe beauty stands in a special relationship to truth. Many contemporary and past scientists have defended the idea that a beautiful theory is more likely to be true, and if faced with a choice between two theories, the simplest or more beautiful theory should be epistemically privileged. A known defender of this idea is Paul Dirac, whose defence of the general theory of relativity was motivated by his inherent belief in the epistemic import of beauty. He claimed that “one has a great confidence in [a] theory arising from its great beauty, quite independently of its detailed successes”, continuing that “[o]ne has an overpowering belief that [the theory’s] foundations must be correct quite independently of its agreement with observation” (Dirac 1980, 40). Such convictions were shared by many physicists at the time, including Eddington himself as well as Werner Heisenberg, who claimed that “[i]f nature leads us to mathematical forms of great simplicity and beauty we cannot help thinking that they are “true”, that they reveal a genuine feature of nature” (Heisenberg 1971, 68). In a similar manner, in his 1979 lecture “Beauty and the Quest for Beauty in Science” presented at the Fermi National Accelerator Laboratory, Chandrasekhar claims that we should trust scientists with well-trained aesthetic sensibilities, because their aesthetic preferences have epistemic import: “we have evidence that a theory developed by a scientist, with an exceptionally well-developed aesthetic sensibility, can turn out to be true even if, at the time of its formulation, it appeared not to be so” (Chandrasekhar 1987, 64). The beauty of Einstein’s general theory of relativity comes from the achievement of unification of our fundamental concepts of space and time, the concepts of matter and motion with “unerring sense for mathematical elegance and simplicity”, which speaks in favour of its truth (ibid., 71). He argues that the discovery of beauty in nature is the most significant of achievements, that it is an “incredible fact that a discovery motivated by a search after the beautiful in mathematics should find its exact replica in Nature” (ibid., 54).

The debate on the role of beauty in science has taken a new turn recently with two domains in contemporary physics where the question of whether and how beauty should feature in the progress of fundamental physics has received a lot of attention. There are two ways to think about this discussion. First, in the last decades, fundamental physics has aimed to confirm and advance the standard model by (among other things) detect the Higgs boson which the theory had predicted, and to further advance our understanding of fundamental physics beyond the standard model. Part of the quest in the last decades has been to discover ‘SUSY’ particles, these are super symmetric particles that are entailed by the theory. Sabine Hossenfelder observes that the symmetry principle has become something of an imperative in the particle physics community, noting that the Nobel laureate Murray Gell-Mann, whose use of symmetry principles led to the advancement of the standard model and the discovery of the previously unknown particle now called omega minus, has defended the deep connection between beauty and truth (Hossenfelder 2018, 37). But while many remain enthusiastic about the fertility of the symmetry principle and believe we need to invest efforts in building more powerful colliders to discover SUSY particles, others have questioned whether trust in the symmetry principle is well placed. Hossenfelder challenges the contemporary trust in beauty among the community of particle physicists, asking whether beauty might in fact be a systematic bias in contemporary physics, leading physicists to pursue research programmes that are not fruitful (Hossenfelder 2018). Second, again in contemporary high-energy physics, our theories are becoming concerned with energy ranges that are impossible in principle to subject to test. The discussions surrounding the status of string theory concerns exactly whether we should trust the theory given its non-empirical status, with Richard Dawid (2013) calling us to redefine the scientific method to accommodate for what modern physics looks like, claiming that non-empirical constraints should be introduced to guide trust and acceptance of theories in the ‘post empirical’ stage of science. This discussion has led us to consider the demarcation question anew, with Silk and Ellis (2014) asking whether string theory, as a theory that cannot be empirically confirmed, should even be taken to be genuinely scientific. They express concerns with the contemporary use of aesthetic ideals and other non-empirical considerations among the physicist community, arguing that such “breaking with centuries of philosophical tradition of defending scientific knowledge as empirical” is dangerous and calls into question the integrity of science (2014, 321).

It is easy to see why the debate on the role of aesthetic ideals in science has become so prominent in contemporary high-energy physics, with so much at stake. This leads us to the question of how we can justify the epistemic significance of aesthetic values: should we trust beauty to be something beyond a heuristic and motivational tool? One way to respond to this question is to argue that beauty is a learned ideal, one that scientists acquire through practice by working with successful theories. We can argue that our aesthetic ideals are ultimately shaped by our education and practice. James McAllister (1996) calls the formation of aesthetic values that a community collectively establishes an ‘aesthetic canon’. The idea is that scientists learn to operate with such aesthetic canons and while those canons are based upon reflections on the successful theories of the past and present, the canons help to mould and shape decisions and confidence in new hypotheses and theories. Let’s explore these ideas with an example. We could claim that a reflection on our past successful theories that exhibited empirical success can justify confidence in trusting unity, since our best theories in physics achieved high levels of unification. Copernicus unified terrestrial and celestial phenomena in one planetary framework, Maxwell unified electric and magnetic phenomena, Einstein unified gravitational and inertial mass, and the concepts of space and time into a spacetime continuum. This reflection serves to boost our confidence in the unifying power of theories. As Richard Boyd (1984) has argued, such reflection on the aesthetic features of past successful theories helps us evaluate the plausibility of new hypotheses, by establishing whether they fit our aesthetic canon (to use McAllister’s term). Thus, according to this account, one could be confident about the plausibility of new theories even before they are confirmed by the evidence, if these theories fit our aesthetic canon[[4]](#footnote-4).

In *Lost in Math*, however, Hossenfelder questions such inferences. She recognises that beauty can play a diversity of roles in science, from a motivator and guide to research, to generating feelings of reward in a scientist, but she also argues that often beauty can be a very systematic bias in a scientific community that needs to be identified, evaluated and amended for if found to go against community goals. Hossenfelder reflects on the track record argument, often implied by contemporary physics, suggesting that their “faith in beauty’s guidance is built on its use in the development of the standard model and general relativity; it is commonly rationalized as an experience value: it worked so it seems reasonable to keep using it” (2018, 26). But against such track record arguments, she draws our attention to the fact that some of our most successful theories have failed to fit our aesthetic ideals, while other much beloved theories that fitted those ideals have failed to gain empirical support. Hossenfelder argues that “not only does the history of science thrive with beautiful theories that turned out to be wrong, but on the flipside we have the ugly ideas that turned out to be correct” (2018, 31).

We can certainly reflect on the history of science and see beautiful theories that we do not regard to be true. Copernicus’ heliocentric system was abandoned in favor of Kepler’s despite the initial resistance to replace perfect cycles for epicycles. Newton’s theory of gravitation is considered unifying and beautiful but also is at best an approximation. Aristotelian biology has simplicity and scope, but is false. Darwinian evolution lacks the clear boundaries between species and adds chance in their evolution, which is much messier than Aristotelian appeal to telos and essence and proper function. Unificationist projects in high-energy physics have been abandoned due to difficulties despite their aesthetic appeal, with the Kaluza-Klein theory providing a beautiful, elegant way to unify gravity and electromagnetism but abandoned. There is also the problem with some contemporary theories that are very successful, but seem to fail our aesthetic requirements. Our most successful theories, the standard model and quantum mechanics, are often regarded as inelegant and lacking aesthetic appeal. Kaku and Thompson observe that the standard model might be our most empirically successful theory, but it is ultimately also one of our ugliest theories, claiming that 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, 75). It seems that replying on such track record arguments can go both ways, we can look at the history of science to find beauty failures and ugly successes, but such arguments are ultimately inconclusive (Ivanova (2020)).

Earlier I also noted that contemporary discussions on the status of string theory are also a place where non-empirical evaluation has received a lot of attention. Dawid advocates that theories like string theory need to be evaluated on non-empirical grounds, but has been cautious when it comes to employing aesthetic factors, on the grounds of being subjective and contingent. Dawid takes aesthetic values to be psychological and contingent in nature, and for this reason aims to offer more formal arguments that can boost our confidence in a theory. Specifically, Dawid (2013) argues that our trust in string theory is justified on the following (philosophical) grounds: (1) No Alternatives Argument: despite systematic attempts, there are no viable alternatives to String Theory; (2) The Argument of Unexpected Explanatory Interconnections: String Theory has explanatory success beyond its originally-intended domain of application; and (3) The Meta-Inductive Argument: String Theory is part of a research programme that has a long record of success. All of these arguments, however, can be disputed. First, is our failure to conceive of alternative theories grounds for justification? Kyle Stanford’s (2000) argument from unconceived alternatives might suggest otherwise. The argument questions whether our collective failure to conceive of an alternative explanation at a particular time, should guide our trust in its (approximate) truth. The argument appeals to a long list of past cases where the scientific community had not been in a position to entertain an alternative (and better) explanation, for instance Aristotelians failed to conceive of the concept of action at a distance, but this failure had nothing to do with the truthlikeness of the agreed upon explanation. Second, is it the case there are no viable current alternatives to string theory? Some think there are indeed alternatives – loop quantum gravity – but there are important social factors effecting their development Smolin (2006). Ellis and Silk (2014) further argue that “[w]e cannot know that there are no alternative theories. We may not have found them yet. Or the premise might be wrong. There may be no need for an overarching theory” (2014, 321). Third, is unexpected explanatory success to be taken as more significant to pure accommodation? The epistemic asymmetry presupposed here between novel prediction and accommodation has been called into question too, identifying the often-contingent factors that lead to a prediction being considered novel (Barnes (2008)). But what is perhaps most interesting in this discussion is whether Dawid succeeds in avoiding the problem he levied at those who defend String Theory on aesthetic grounds. It is not clear that our judgements of explanatory success, for example, are free from aesthetic and other subjective values, so it can be argued that perhaps the aesthetic values come into play within Dawid’s framework too, just at another level of analysis.

It is clear that today, perhaps more than ever, scientists are faced with choices that inevitably involve aesthetic considerations and these choices go way beyond the choice of what theory to pursue and develop, the aesthetic values seem to be playing a much more substantial role in shaping the community’s trust in theories and their confidence in research programmes. This section explored one way to justify such trust, by exploiting the track record of beauty in the success of science, but we also saw that such arguments suffer from selection bias and can well be made to defend the very opposite conclusion. In what follows, I will reflect on how scientific progress, and the way science evolves, might change the kinds of questions we focus on when it comes to aesthetic values in science.[[5]](#footnote-5)

1. Science, progress and aesthetic values

Before we begin our reflection on the new questions about aesthetic values that emerge in science today, I want to clarify how the accounts we explored earlier on whether aesthetic values are truth indicative, heuristic, or motivational relate to accounts of scientific progress. The question is whether our commitments about the role of aesthetic values in science also commit us to a particular construal on what scientific progress consists in. Scientific progress can been understood in several ways: (1) in terms of increasing knowledge (epistemic approach), developed originally by Burry (1920) and more recently by Bird (2007); or in terms of increasing verisilimitude (semantic approach), developed by and Niiniluoto (1980) and Rowbottom (2008); (2) as an increase in problem-solving abilities, developed originally in Kuhn (1962), Lakatos (1968), Laudan (1981) and more recently by Shan (2019); and (3) as increase in understanding, developed by Dellsén (2021). We can see an obvious parallel in how progress is construed with the role of aesthetic values in science. Taking aesthetic values to be truth-indicative is continuous with taking progress to be the increase of verisimilitude or knowledge. Taking aesthetic values to be convenient, heuristic or motivational tools is continuous with the functional construal of scientific progress, and taking progress to be the increase of our understanding is continuous with taking aesthetic values to be conditions of our understanding. Despite the clear parallel, our stance on these two questions does not necessarily have go hand in hand. That is, our stance on the epistemic significance of aesthetic values does not impose a particular commitment to scientific progress; one could easily commit to any other combination. For instance, one could commit to taking scientific progress to be construed as increase of knowledge but when it comes to aesthetic values, deem them purely instrumental or motivational, rather than truth-tracking. And while these combinations have not yet been explicitly explored in the literature, it is particularly interesting to consider whether construing aesthetic values as constraints in our understanding, as developed by Elgin (2020) and Ivanova (2020), blends in interesting ways with Dellsén’s (2021) account of scientific progress.

With this caveat in mind, let us explore some new questions concerning the role of aesthetic values that emerge currently in science. Has the role of aesthetic values become more prominent in post empirical physics? Are such factors going to be features of future science or are they going to be eliminated from future reasoning, as the positivist envisioned? Science is a human activity, so it seems plausible to assume this activity will continue to reflect our goals, values and aims. But with the emergence of computer assisted discoveries, and AI now being part of scientific practice, should we expect the debate surrounding aesthetic values to change and how?

We have seen above that as science evolves, its methods have also changed. Traditionally empirical domains are now entering a post-empirical phase. On the other hand we are also living in the age of big data. We now produce data in abundance and by a variety of sources, from agriculture and weather forecast; to transportation and the devices we use in our daily life. A variety of interesting questions with regard to the epistemology of big data have recently received systematic attention (Leonelli and Tempini (2020), Pietsch (2021)). It has become clear that the way in which scientists use big data is very much dependent on their values and aims, with data travelling from different domains and applications to serve plurality of goals. It remains to be studied how aesthetic considerations affect the selection, evaluation and utilization of big data, but some initial insights are worth mentioning. Leonelli (2020) for instance is apprehensive about the significance of elegance in biology, given that complexity is often more appropriate for capturing facts about biological systems. This is an important point, since it questions whether we can have a universal set of aesthetic values, rather than domain-specific ones, that can very much be found in conflict with each other (Ivanova (2017a)). On the other hand, Dykes and Wood (2009) explore how beauty can emerge from big data by uncovering underlying patterns and unexpected connections, resonating with how other thinkers, such as Poincaré, have previously construed the role of beauty in science (Ivanova 2017b)).

As science evolves we also see that much of the practice of science is now delegated to intelligent machines. AI is now successfully used in data extraction and data mining, in the design and implementation of certain experiments, and it has even led to some surprising discoveries. One such discovery was the much-celebrated recent prediction of protein folding by Deep Mind’s Alpha Fold. Many interesting questions emerge. For one, we need to re-evaluate the role of AI in our discoveries – should we attribute creativity and thus credit AI for scientific discoveries? We could say that currently AI lacks the level of independence required for credit in discoveries, perhaps its role can be paralleled to those of technicians, which in itself opens an interesting door for exploration of our creditation practices. Claire Anscomb (2020) has recently explored the notion of discovery as a collective practice, asking whether technicians and assistants who enable the production of an artwork or a scientific discovery deserve credit and recognition, arguing that creative autonomy should be at the center of our credit attribution in science and art. This leads us to consider whether AI will require creative credit in computer-assisted discoveries and whether AI can be creative[[6]](#footnote-6) in designing scientific experiments. Another interesting consideration is also whether machine-learning algorithms will exhibit similar aesthetic preferences to those seen in human reasoning (Lombrozo (2016)), and whether computer-assisted discoveries will be valued in a similar way to human discoveries. If we construe of aesthetic values as constraints imposed by human agents of particular capacities, it is perhaps to be celebrated that AI will not exhibit these constraints. But one reason for which one could be sceptical about the aesthetic value of computer-assisted discoveries comes from the reaction of mathematicians to the computer assisted proof of the 4-colour theorem by Appel and Haken, an example of the method of proof by cases. While the discovery has certainly been of great epistemic significance, mathematicians have argued that the proof is ‘ugly’ and lacks the aesthetic merit of human discoveries (Montano (2014)). Why is that? The computer-assisted proof operates with a ‘bottom up’ approach: it scans around 2000 cases in an important step in the proof. This approach is considered aesthetically and cognitively inelegant. As Montano argues, mathematicians consider this proof to go against the simplicity of traditional mathematical proofs, and this aesthetic constraint has a cognitive dimension “simplicity facilities understanding the proof, while complexity hinders it“ (2014, 36).

This leads us to consider the role of aesthetic value from a different perspective. Aesthetic values play a cognitive role not in the traditional way, seen as linked to truth, but as cognitive constraints agents impose on their reasoning. Recently, attention has been given to the traditional question of what constitutes the aim of science: acquisition of truth, or in gaining understanding, which can be possible even in the absence of truth. This in its turn has also given rise to reconsidering what constitutes scientific progress (discussed in the first chapters of this book). Elgin (2018) and Potochnick (2016) have argued that we cannot accommodate for the use of idealisations and modelling in science if we construe the aim of science to be truth, given that models and idealisations often make successful predictions by making knowingly false assumptions about the target system. What these models allow us to do, however, is gain understanding and manipulate the system, which they see as the ultimate goal of science. Within this framework, we can construe of the role of aesthetic values as constraints on our reasoning, which we impose on our explanations, models and theories, in order to gain understanding of the world. Aesthetic values function as constraints on the kind of reasoning we engage in, what theories and hypotheses we develop and ultimately operate as ‘gatekeepers’, reflecting human facts about human capacities rather than the world (Elgin (2020), Ivanova (2020)). This does not mean that they need to be seen as rigid. We can accept hypotheses and explanations that conflict with our aesthetic values (Lombrozo 2016, Elgin (2020). Values can be updated and re-evaluated in light of their performance and success in practice, as argued originally by McAllister (1996), and more recently by Turner (2019) and Currie (2020) who see the use of aesthetic values to form an ‘epistemic feedback’ effect, which ultimately grounds and justifies the use of such values. But whether the aesthetic values operating in current science will continue to form prevalent constraints in our sciences, whether machine algorithms are going to break away from such constraints and offer epistemic goods inspite of this, and what this will imply for the role of aesthetic values in science, remains to be seen.

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1. Inspirationalist accounts go back to antiquity, where the production of artwork was credited to inspiration of the Muses, during the romantic period creativity is understood in light of divine inspiration. For an overview, see Gaut (2010). [↑](#footnote-ref-1)
2. For a recent overview of the debate on values in science and objectivity, see John (2021). [↑](#footnote-ref-2)
3. Different accounts have been proposed regarding the aesthetic appreciation of nature. For a detailed discussion see Carlson (2011), Parsons (2002) and Turner (2019). Brady (2011) also defends that we can aesthetically engage with objects in nature that are not beautiful. Wraggle-Morley (2020) explores how natural philosophers, were committed to the idea that nature is beautiful due to being a product of divine creation, reconciled their belief with the existence of ugly or displeasing natural objects. [↑](#footnote-ref-3)
4. While James McAllister aims to show that it is rational to use aesthetic values in science, Richard Boyd is concerned with the claim that the virtues of a theory can be truth indicative and justifying our believe in a theory’s truth. The analogies of their views are explored in (Ivanova (forthcoming)). [↑](#footnote-ref-4)
5. It is worth noting that in the above discussion we made a certain assumption: that the aim of science is epistemic, construed either as achievement of empirical adequacy, truth or understanding. One could, however, claim that the aim of science is to deepen and enhance our aesthetic engagement with nature and our epistemic advances in science are supplementary to this primary aesthetic goal. [↑](#footnote-ref-5)
6. Whether AI can be creative has been explored recently after Deep Mind’s Alpha Go beat the Go world champion player. Halina (2021) analyses whether Alpha Go was creative, arguing that whereas the programme did not exhibit domain generality, the Monte Carlo tree exploration and the ability to make a highly unexpected and surprising move, makes Alpha Go meet some minimal requirements for creativity. [↑](#footnote-ref-6)