

The aesthetics of scientific experiments

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Abstract

This article explores the aesthetic dimensions of scientific experimentation, addressing specifically how aesthetic features enter the construction, evaluation and reception of an experiment. I highlight the relationship between experiments and artistic acts in the early years of the Royal Society where experiments do not serve only epistemic aims but also aim to generate feelings of awe and pleasure. I turn to analysing which aspects of experiments are appreciated aesthetically, identifying several contenders, from the ability of an experiment to uncover nature's beauty, to encapsulating original designs and human creativity. Following this analysis, I focus on the notion of beauty: what makes an experiment beautiful? Several common qualities are explored, from the simplicity and economy of the experiment, to the significance of the experimental results.

1 | INTRODUCTION

There has recently been an influx of interest in the relationship between aesthetics and science. Specifically, some philosophers have explored the role of beauty in scientific theorising, how it affects the generation of theories and the evaluation of their tenability and explored the relationship between beauty and epistemic aims such as truth and understanding (see Breitenbach, 2013; Elgin, 2020; Hossenfelder, 2018; Ivanova and French, 2020; Kosso, 2002, McAllister, 1996, & Ivanova 2017a, 2020, among others). The primary focus of these works has been the relationship between theories and aesthetic values. However, there is also important reflection on how aesthetic judgements affect scientific practice outside of theory construction and evaluation. For instance, Wylie (2015) and Turner (2019) engage with aesthetic factors in the preparation of fossils and studying the deep past, Currie (2020) argues for the significance of aesthetic judgement in a plurality of scientific practises, Parsons (2012) studies the role of aesthetic

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factors in chemical biology, Elgin (2014) and Murphy (2020) explore aesthetic considerations in thought experiments and Parsons and Reuger (2000) offer an insightful study on aesthetic appreciation of scientific experiments.

My aim in this article is to engage with aesthetic aspects of scientific experimentation, specifically with how aesthetic features enter the construction, evaluation and reception of an experiment. I will start with the origins of scientific experimentation and illustrate the relation between experiments and artistic performances, arguing that from the early 17th century, we can appreciate the aesthetic nature of experiments and their aim to generate not only knowledge of nature but also an aesthetic experience in the audience. In Section 3, I turn to analysing which aspects of experiments are appreciated aesthetically, identifying several contenders from the ability of an experiment to uncover nature's beauty, to encapsulating original designs and human creativity. Following this analysis, in Section 4, I focus on the notion of beauty: what makes an experiment beautiful? I analyse commonly noted qualities such as simplicity and economy. In Section 5, a further aspect of an experiments' beauty is explored: its results. Often, experiments are considered beautiful when they lead to a discovery. I explore the philosophical implications of this view by focusing on the diversity of roles experiments play in science and their epistemic import.

2 | EXPERIMENTS AS ARTISTIC PERFORMANCES

Looking into the history of science and the origins of experimentation, we find clear links between scientific experiments and artistic acts. Experimentation took central stage at the time of Francis Bacon and members of the Royal Society of Science, such as Robert Hooke and Robert Boyle, who performed their experiments in front of audience, reflecting not only on the experimenter's aims but also at the experience of the audience, which is often characterised as awe inspiring and aesthetic in nature. Joseph Priestley's reflections on experiments studying electricity are instructive. Priestley often refers to these experiments as beautiful, generating in the audience awe and pleasure. His insights help us situate the role of the experiment in his time and the role of the experimenter. While the skill and 'genius' of the experimenter are often acknowledged, what seem to be the ultimate generation of aesthetic pleasure is the experimental outcome. For instance, when describing Watson's experiments on electricity using a large vacuum cylinder and well insulated copper plates that were electrified to observe the behaviour of the electric current, Priestley claims that this is 'one of the most beautiful experiments' generating 'the most delightful spectacle' (1775, 298). The aesthetic pleasure and delight are not generated so much by the very construction of the experiment, the materials used or the steps implemented to study the phenomenon although these are also acknowledged as beautiful, skilful and creative. What receives particular attention is the observed phenomenon and the beauty of the electric effect, which he compares to the aurora borealis. Priestley often refers to the aesthetic experience generated during these experiments, citing pleasure, awe, amusement (ibid., 504–506).¹ The idea that experiments afford aesthetic experiences seems to have played a particular role in experimentation of the 17th and 18th century. The emphasis on the experience of the audience and the setting of the experiments is telling as to how experiments were treated as artistic performances. According to Parsons and Reuger, 17th–18th century experiments were found to be aesthetically pleasing or beautiful because they 'made visible particular aspect of the beauty of nature itself' (2000, p. 409). Parsons and Reuger stress that during this experimental period, the aesthetic appreciation of the experiment is due to its ability to uncover nature's beauty. The assumption that nature is beautiful has been commonly made by scientists, some examples include Bacon, Newton, Dirac and Einstein (see Ivanova, 2017a, 2020). What is noteworthy for the scientists of the 17th and 18th century is the impact this presupposition had on their practises. Parson and Reuger argue that during the early years of the Royal Society, the natural philosophers were not focusing on the 'skill and economy manifested in the artefact but rather the economy of nature itself' (2000, 409). So, while the experiment itself could be appreciated for its simplicity or beauty, what was really appreciated and was the focus of the attention during an experimental display was the unveiling of nature's secrets.

Alexander Wragge-Morley's recent (2020) study of the aesthetic considerations driving the members of the Royal Society in this period is instructive. He documents the aesthetic considerations at the forefront of natural philosophers, from the preparation of specimens, the design of experiments, the formulation of hypothesis and emphasises that these practises were deeply impacted by the belief that nature itself is beautiful, which in itself was grounded in the belief of a divine creator. For instance, the illuminating study of Hooke's *Micrographia* (1665) illustrates the idea that simply reproducing the data of experience of specimens was considered unsatisfactory that one had to provoke a feeling of pleasure and beauty when looking at the scientific object, thus producing a beautiful image. Examples of the artistic presentation of the object of scientific investigations are illustrated in the work of Hooke's depiction of the flea as seen under the microscope and Leonardo Da Vinci's presentation of the human body in his sketches, to name a few. While this period continues to see the advancements of new instruments and the ability to access previously inaccessible aspects of nature, a shift in methodological perspective seem to have correlated with a shift in focus on the aesthetic features of experiments. The next section explores this shift.

3 | FROM UNVEILING NATURE'S BEAUTY TO UNCOVERING HUMAN GENIUS

With the advancements of new instruments, techniques and methods, one of the central aspects of aesthetic appreciation becomes the experiment itself signifying a shift from valuing the experiment for revealing nature's beauty to valuing the design of the experiment, the way the experiment was constructed for a specific purpose. Attention starts being given to the imagination and creativity of the experimenter, the 'genius' in the construction of the experiment and its fit for the aims of the scientists. The primary focus of aesthetic appraisal is no longer nature itself, but rather the artefact. Parsons and Reuger (2000) see this change of aesthetic value to coincide with the change of scientific methodology. They see scientists such as Priestley, for instance, who claim that we should not focus on the design of the experiment itself but rather the beauty of nature that becomes unveiled in the experiment, to be guided by an inductivist methodology, affecting the role they assign to the experiment. The aesthetic appreciation of experiments changes substantially between the late 18th and mid-19th century driven by methodological shifts in the practice of science. While earlier experiments are performed to study nature and were repeatedly performed following the inductive method, shifting to the hypothetico-deductive method directs towards experiments serving the purpose of testing the correctness of theories. This methodological change, according to Parsons and Reuger, also shifts the way in which experiments are appreciated aesthetically. For a while in the 17th century what is being appreciated is mostly the unveiling of nature's beauty, the phenomena produced in the experimental settings, now what is being appreciated is the skill and design of the experiment. As Parsons and Reuger argue:

[N]ow it is only with the assistance of the confirmed or illustrated theory that an experiment is thought to give us insight into nature. Whatever beauty is displayed in an experiment, it cannot be the beauty of nature itself; the economy of an experiment reflects the economy of our own cognitive households, not the economy of nature. This is clearly different from the view of the eighteenth-century natural philosopher who appreciates nature itself through the frame of the experiment. (ibid., 411)

Parsons and Reuger appeal to Allen Carlson's (1993) distinction between order-oriented and design-oriented appreciation, a distinction they think reflects the two modes of appreciations we see in the early 17–18th century and the later 18–19th century traditions. What comes to be aesthetically appreciated in the later tradition is not nature's beauty itself, but the display of "aptness" in the relation of result and tools, of plan and 'success' (ibid., 411). The experiment is now beautiful because it displays human imagination and creative thinking. Importantly, the experiment is considered beautiful when it is 'optimally suited to achieve its purpose' (ibid., 411–412). This latter

form of appreciation allows for the success of the experiment to be construed as aesthetically pleasing and giving rise to aesthetic experiences. This takes us to explore the notion of beauty in experiments next, specifically their simplicity, economy and elegance.

4 | WHAT MAKES AN EXPERIMENT BEAUTIFUL?

The beauty of scientific theories is often analysed in terms of aesthetic properties such as simplicity, elegance, symmetry (McAllister, 1996, Ivanova, 2017b). For instance, Newtonian mechanics is often praised as simple because it can describe the motion of bodies with three rather economical laws of motion and a law of gravitation featuring few parameters. The general theory of relativity is considered simple because it offers an economical way of understanding the concepts involved in describing motion and forces by unifying gravity and inertial mass, the concepts of space and time into a space-time continuum, so in this way it provides us with simpler and more unified understanding of gravitational phenomena. There is, of course, a plurality of ways in which we can understand simplicity and other values, but as a starting point in our investigation the question is whether similar properties seem to be associated with scientific experiments.²

Many experiments that are considered beautiful are praised for their economy, simplicity and elegance. Indeed one definition of an aesthetically pleasing experiment, given by Parsons and Reuger (2000) is that the experiment utilises the minimal material for the most use:

An experiment now is aesthetically valuable because it shows 'aptness' in relation of result and tools, of plan and success; it is a beautiful artefact, a manifestation of human ingenuity, an instrument optimally suited to achieve its purpose. What is appreciated is, for instance, the simplicity of the arrangement, its economy, or its ability to unify several tasks in one display. (*ibid.*, 411–412)

Economic and simple arrangement and aptness for purpose seem to have been common themes in the praise of many beautiful experiments, such as Richardson's experiments on the electron (Galison, 1987, p. 247) or Rutherford's experiments on the artificial disintegration of atomic nuclei (Kapitsa, 1937, p.90). Even in the case of thought experiments, simplicity and aptness seem to be at the forefront of appreciation. Brown, for instance, argues that Galileo's thought experiment of falling bodies is 'the most beautiful thought experiment' due to its simplicity and originality (2004, p. 24). Of course the materials employed between thought experiments and physical experiments are different, as Alice Murphy (2020) stresses, but the emphasis of aesthetic praise in both domains seem to be on the simplicity of the design.

Reflecting further on the notion of simplicity, we find a number of different aspects being praised as beautiful: simple and clear results, conceptual simplicity and elegance, minimal steps and the significance of the result. Let us illustrate these with a specific example of what has come to be regarded as 'the most beautiful experiment in biology', a claim made by John Cairns about the famous experiment performed by Meselson and Stahl (1958). After the 1953 discovery of the structure of DNA molecules, the question that needed addressing was how the DNA replicates. Three different mechanisms were proposed: (1) conservative replication, proposed by Gunther Stent, according to which each of the two strands of the parent DNA molecule are replicated in the new; (2) semi-conservative replication, proposed by Watson and Crick, according to which one strand of the parent DNA is conserved in the daughter DNA; (3) dispersive replication, proposed by Lehninger, suggesting that the parent DNA chains break at intervals with the parental segments combining with new segments to form the daughter DNA. Meselson and Stahl performed an experiment that supported the semi-conservative replication. They fed bacteria nutrients containing heavy nitrogen isotope. Through metabolising, the nitrogen was slowly incorporated into the bacterial molecules. Meselson and Stahl continued the process until the genetic material of the bacteria became heavy. They then fed the bacteria light nitrogen and studied the genetic material of the bacteria through the next

generations. They used a new method, ultracentrifugation, which allowed them to separate light from heavy genetic material. The ratios they obtained of light heavy and hybrid DNA were compatible with the semi-conservative replication and not with the conservative or dispersive model of replication.

Why have so many scientists praised this experiment as beautiful, elegant and claimed it provokes an aesthetic response? One aspect that has been noted is the design of the experiment itself, the elegant idea behind how Meselson and Stahl set up the experiment. Ernst Peter Fischer argues that:

One condition of this experiment consisted in making the genetic material physically heavier without changing it chemically. There is something beautiful in this idea alone, the understanding that the chemical properties of an atom—for example, its ability to bond with other atoms—are determined by its external electrons, whereas the physical properties—for example, the mass—are hidden inside the atomic nucleus (1999, 21).

The simplicity of this experiment is also explored by Holmes, who emphasises the role this simplicity plays in the communication of the results to students:

The beauty of the Meselson–Stahl experiment is invariably connected with its simplicity. When reduced to its essential features, it is readily understood even by beginning students of the life sciences. Teachers look on it with fondness for the ease with which its message can be conveyed (2001, ix).

Holmes (2008) discusses several scientists who praised the simplicity of the experiment because it could easily be visualised by students, the steps were easy to grasp, and the results and significance of the experiment were easy to appreciate (*ibid.*, 427). He argues that the Meselson–Stahl experiment is seen as a model experiment and is regularly used as an educational tool for instance in the introductions to molecular biology. Scientists have different insights into the value of this experiment for educational purposes.

Connected to the above is the praise of the obtained results themselves, numerous scientists claim that the results are 'clean' and 'easily understood' that the relationship between the aims of the experiment and the result was so clear that there was no need for replication, they spoke in defence of the semi-conservative replication model. Stahl himself notes that the results exhibit notable clarity in the sense that there is no need for their interpretation so they exhibit a sense of completeness and conclusiveness. As Homes notes, James Watson noted that the results spoke for themselves, giving a simple answer to a question (*ibid.*, 411)³. Fischer similarly argues that 'the Meselson–Stahl experiments speak for themselves and made all further commentary superfluous' (1991, 21).

Last, it is important to note a further aspect that has been regarded as beautiful, which concerns the involvement of innovative materials and original, unexpected steps in an experiment. For instance, in the case of Meselson–Stahl, the use of centrifugation was innovative in this very step in their design was regarded as beautiful. Such sentiments towards novel involvement of materials and methods can certainly also be noted in experiments going back to studies of the vacuum, utilising the air pump, to using complex technologies and artificial intelligence in modern high energy experiments in physics. The important point to stress is that these show the involvement of innovation, creativity and imagination of the experimenter themselves, which brings us back to Reuger and Parson's distinction between content and design-oriented appreciation.

With this non-exhaustive list of values associated with beautiful experiments, we can ask the question whether we have grounds to take these values to be stable across different scientific disciplines or time periods. As we saw already, the aspects of appreciation have changed in new experimentalist traditions, so what does this imply for the above-mentioned values? Here we go back to Pierre Duhem (1906) and Thomas Kuhn (1960)'s insight that the values of theories tend to change from schools of thought, traditions and periods, and we should not expect them to stay unchanged. The lesson from James McAllister's work further illustrates that we can expect aesthetic revolutions in theory change with new values becoming prominent while others losing their centrality. However, some

philosophers emphasise a certain continuity when it comes to the core values of theories (and extending to experiments). Peter Kivy (1991), for instance, observes that scientists almost never seem to praise non-classic features in their products, rather their tastes remain pretty classic. Similarly, Ullian Montano (2012) argues that some aesthetic values, such as simplicity and elegance, are 'historical constants', not losing centrality in scientific practise. Ivanova (2020) explains this resistance to revise aesthetic canons and the stability of certain features as grounded in cognitive capacities. Parsons and Reuger (2000) propose that while McAllister's thesis is compatible with the classicism in the scientific community, it does not explain it. They argue that by appreciating the change of focus of aesthetic appreciation in the 18–19th century, when experiments start being praised for the simplicity of their design, and we acknowledge the epistemic role they start playing, we can explain their 'relatively immune to historical change'. Parsons and Reuger introduce the term 'operational simplicity', which they claim can be related to the epistemic success of the experiment, as 'an experiment is operationally simple if it consists of few operations or experimental steps' (ibid., 413). I think this concept has the potential to accommodate not only the experiments on the 18–19th century that concern Parsons and Reuger's exploration, but can also be fruitfully employed in modern day complex experiments where the concept of simplicity might appear at first sight not to apply.

5 | BEAUTY, DISCOVERY AND EXPERIMENTAL AIMS

Above we noted that some of the reasons why an experiment was considered beautiful are due to the fact that it led to a discovery and advancement of our knowledge. As we saw in the previous section, this sentiment was widely expressed by scientists regarding the Meselson–Stahl experiment supporting the semi-conservative replication. In his exploration of beautiful experiments Robert Crease (2002) argues that an experiment is beautiful only when it shows something new, if it leads to the discovery of a new particle, force or phenomenon. In this section, I explore some of the philosophical implications of this claim.⁴

The claim that a beautiful experiment is the one that leads to a discovery is not difficult to motivate. Novelty gives value to the experiment independently of its particular properties. Being novel matters so much in science and in art. For instance, our entire reward structure in science, as the sociologist Robert Merton famously observed, is centred around novelty. We reward those who discover first and not those who replicate, science is driven by what has become known as 'the priority rule' (Strevens, 2003). For this reason, it is no surprise that experiments that lead to discoveries are at the centre of aesthetic appreciation. Two experiments might exhibit the same aesthetic properties, but the experiment that is first to obtain the result is the one that has special significance. Similarly, in art we do not value forgeries or copies, even if they are skilfully carried out; we value originals. This calls us to consider the creativity involved in constructing experiments that lead to discoveries. Holmes (2008), for instance, draws our attention to the immediateness of the results obtained in the Meselson–Stahl experiment, arguing that the experiment was constituted by a 'singular historical event', observed by the individual scientist, it was not repeated afterwards (ibid. 431). This is an important observation, but Holmes himself recognises that many experiments in science will not exhibit such simplicity and immediateness of the obtained results⁵. Take, for instance, experiments in high-energy physics. The experiments stretch over the borders of countries, involve thousands of scientists and timely analysis of the obtained data. We cannot by the stretch of the imagination claim the scientists directly or immediately observe an experimental outcome, since analysing the outcome of a measurement is a complex process of statistical analysis and deciding whether the experimental data constitute an 'event' in itself is a laborious work that takes substantial time to settle, as Beauchemin's (2017) insightful study of the analysis of data obtained by the ATLAS detector at the LHC reveals.

If we focus on certain types of experiments and scientific periods, as Parson and Reuger do, we could claim the discovery has immediacy and can be perceived by the individual. But, oftentimes discoveries are messy and complex events. Discovery is hardly a unique and well clear-cut event. Many discoveries span over a few years before the community reaches a consensus to consider the experiment ended. Looking at the discovery of the Higgs boson, Mättig and Stöltzner (2019) also emphasise the laborious process and timespan of deliberations when deciding

whether the data collection at the LHC indicated an event, and whether the event constituted a discovery. Peter Galison's illuminating work on the discovery of positrons, for instance, further illustrates that not only settling the date of the discovery is not straightforward, the discovery can be credited to a number of experimental groups. As Galison insightfully notes in his *How Experiments End*, when asked the question 'When was the neutrino discovered?' we can give a variety of answers with several research groups deserving credit for the discovery. This brings us to the next concern, and that is the contingency of discovery. This certainly brings the question as to who is the creative, individuals or communities. While traditional studies of creativity have analysed it in terms of individual inspiration, computation or epistemic virtue, recently the question that has been placed in the context of big science and collaborative discoveries as to whether creativity is a property or virtue of communities rather than individuals (Ivanova and French (2020), Currie (2019)). Simon Shaffer (1996) has also extensively highlighted the contingency behind discoveries in science, challenging our idea that our practises of credit attribution are justified towards those who discover 'first'. This fact calls us to consider exactly what we value when it comes to the aesthetic nature of the experiment and where we are going to identify this value.

I also want to suggest that the attribution of aesthetic value to experiments that lead to novel results belongs to a particular image of experimentation that is rather restrictive. Experiments are performed with a plurality of aims, not always in the search to confirm the existence of a particle or phenomenon but to explore new domains. For instance, one of the aims of the LHC experiments certainly were to offer support to the standard model by finding a particle the theory had predicted. The detection of the Higgs boson in 2014 offered significant support to the standard model that had predicted the existence of the particle. But this experiment has other aims too, it explores and studies previously inaccessible domains, the deep TeV energy range, which is hoped to help in the advancement of physics beyond the standard model. The diversity of aims for which experiments are constructed has been the lesson from the new experimentalist school which emerged in the 1980s. The work of Galison (1980), Catwright (1983), Hacking (1983) and Franklin (1986) sheds light into the many reasons why experiments are carried out, the experimentalist traditions in which experiments are designed and carried out and the ways in which their results are evaluated, with Galison arguing that different schools can reach very different conclusions with regard to what an experimental result entails. Taking this lesson to heart perhaps leads to reconsider the aesthetic values of experiments beyond discovery, which has philosophical implications.

6 | CONCLUDING REMARKS

In this article, I have offered a number of directions we could follow when addressing the question 'What is a beautiful experiment', starting with the very idea that an experiment is aesthetically pleasing when it uncovers the workings of nature and then exploring specific traits of the design of the experiment itself. While elegance, simplicity, clarity and significance of results are usually praised, we saw that there are significant philosophical questions that need addressing if we are to attribute aesthetic values to products of scientific activities, such as the experiment or the discovery it leads to. Last, we have also raised questions about the very idea of the purpose of experiments, whether aesthetic value is to be attributed only to experiments that discover, and noted some challenges regarding the nature of creativity.

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ENDNOTES

¹ Defining an experience as aesthetic in nature and delineating it clearly from other experiences has been a difficult task. Noël Carroll (2002) distinguishes between *axiological*, *content* and *affect* oriented approaches. On the axiological approach, an aesthetic experience is worth having independently on any instrumental value. The content approach seeks

to identify common qualities in the object generating the experience, while the affect approach focuses on the qualities of the experience itself (see Beardsley, 1982 for an affect oriented definition). One might be skeptical that when it comes to science, the aesthetic judgements are indeed of aesthetic nature (Todd, 2008). However, there seems to be good reasons to think so. For instance, McAllister, (1996) argues that the very use of aesthetic language in science should motivate us to take scientists to be reporting aesthetic experiences. Ivanova (2017a) further points out that studies in neuroscience suggest that there is a common experience observed in scientists who engage with works of art or scientific products, such as theories and proofs. Furthermore, aesthetic claims are often made about scientific products that do not meet epistemic goals, such as theories that have not been empirically supported yet, making it difficult to argue that the aesthetic judgements can be translated away as judgements about epistemic success (Ivanova, 2020). For the purposes of this article, I will grant that there is an aesthetic experience without committing to a particular definition.

- ² The predominant aim of philosophers has been to establish whether there is an epistemic role for aesthetic values, focusing on whether there is a relationship between the beauty of a theory and its empirical success or even truth (see McAllister, 1996, Ivanova and French (2020) for an overview), or whether beauty is a condition for understanding (Breitenbach, 2013; Elgin 2020; Ivanova, 2017a, 2017b, Ivanova & French, 2020). An interesting avenue to explore is how these concerns transform once our focus is on scientific products other than theories, such as the experiment.
- ³ Tudor Baetu (2019), however, disagrees that the results spoke so clearly in favour of the semi-conservative replication arguing that some of the auxiliary assumptions made by the experimenters needed to receive further support, making the conservative hypothesis still a viable option at the time Meselson and Stahl published the result, condemning it only after further experiments were carried out.
- ⁴ Recently there has been an interesting discussion regarding experiments and surprise (Morgan, 2005; Parke, 2014; Currie, 2018, and French & Murphy, (forthcoming)). While this literature is not making reference to aesthetics, it seems worth thinking about the aesthetic dimension of surprise in experimental outcomes.
- ⁵ As mentioned earlier, Baetu (2020) objects to the idea that the experiment produced such solid results, arguing that the original results were 'fragile' and more work needed to be done to confirm the auxiliary assumptions on which the original experiments relied on.

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How to cite this article: Ivanova M. The aesthetics of scientific experiments. *Philosophy Compass*. 2021;1–9. <https://doi.org/10.1111/phc3.12730>