Aesthetics and Agency in Experiments

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Abstract

The aim of this paper is to place agency front-and-center in the aesthetics of science, in particular, in the aesthetics of experiments. Our strategy is to consider how elements of experimental design serve to generate aesthetic experiences in those carrying out the experiment: in addition to well-designed experiments generating clear, elegant results, they also confront the experimenter with the experimental phenomena, afford the exercise of agency throughout experimental runs, and underlie stable, intersubjective experiences across agents. Taking our queue from C. Thi Nguyen's recent *Games: Agency as Art* (2020), we draw an analogy between experiments and games: both involve artificial practical environments which are designed to give participants an aesthetic experience of their own agency. We apply the account to Newton's optical work and contrast these with contemporary experimental practices, where significantly more 'experimental distance' holds between the experimenter and the result. Taking the agency of experimental practice seriously enables a richer account of the role of aesthetic values, sensibility and judgments in science.

1. Introduction

Aesthetics is often grounded in agential experience and yet the aesthetics of science typically leaves a determined distance between the agency of science and aesthetic value. The majority of work has focused on the properties of theories—their elegance, simplicity, and so on—and the role of agency and agential experience remains unexplored. Recently, some philosophers have sought to expand the scope of the aesthetics of science, asking after a wider variety of scientific practices (Turner 2019; Murphy 2020; Wragge-Morley 2020; Ivanova 2021, 2022; Currie forthcoming). According to such views, science is shot through with aesthetic properties, sensibilities, and judgments, which matter for everything from data generation and preparation, to fieldwork, to the design of experiments (both literal and gedanken) . And yet still in such discussion scientific agency vanishes. Our aim in this paper is to place agency front-and-center in the aesthetics of science. We'll do this via focusing on experiments.

Our way into scientific agency and aesthetics begins with Milena Ivanova's recent work (2021, 2022), which emphasizes the aesthetic properties of experimental design (see also Parsons and Rueger 2000). On her view, experimental beauty lies not only in the significance of its results, but also in how it is designed: beautiful experiments display properties like simplicity, economy, and elegance, in relation to their purpose. Here, we also focus on design, but in a different way. We identify a source of aesthetic value that is rooted in the participant's experience of doing an experiment; well-designed experiments position agents to experience experimental phenomenon and to understand and express the agency the experiment affords.

To capture this agential notion of good design, we draw on C. Thi Nguyen's account of "Suitsian games" (2020). Nguyen (2020) discusses how game designers work in the "medium of agency"; they shape participants' experiences of their own agency i.e., the decisions and actions taken within a practical environment. Although we stop short of claiming experiments are games, we argue that experiments, like games, are an artificial, practical environment and that they can encode agency in the way that Nguyen highlights. This can be part of not only the experiment's aesthetic value but also its epistemic power.

On our view, in addition to producing data, experiments produce aesthetic experiences in the scientists conducting the experiments. Well-designed experiments afford experimenters rich aesthetic agency, and that agency guides both experimental design, experimental runs, and conceptions of experimental phenomena. Although our focus will be on experiments, it will become clear downstream that we think the discussion raises broader questions about the role of agency and aesthetic sensibilities across many arenas of scientific practice.

We'll start in section 2 with a quick tour of discussions of agency in experiments, focusing on Crease's discussion of the double slit experiment—the "most beautiful experiment in physics"—and Pickering's notion of human-world interaction as a "dance of agency". We'll then turn to Nguyen's work on agency and aesthetics in section 3, and we apply this to experiments in section 4 with a focus on Newton's optical experiments. In section 5, we consider an objection to our account that is grounded in the fact that in many experiments, there is a distance between the experimental object and the agent who conducts the experiment. We develop a notion of "experimental distance" which is crucial for understanding the kinds of agency and aesthetic experience an experimental procedure affords. We end by clarifying the scope of our view, and by setting out the ways in which this problem of distance can be overcome.

2. Agency in Science

While agency is as-yet unexplored in the context of recent aesthetics of science, the agency of experimentation plays a central role in some discussions. In this section we'll summarize some of these, opening the way for a closer investigation into the connections between agency and aesthetics in science which we turn to in sections 3 and 4.

As motivation, consider a poll conducted by *Physics World*, the magazine of the Institute of Physics. In 2002, the magazine asked its readers to submit contenders for the "most beautiful experiment in physics". As Robert Crease explains, the winner of the poll was the famous double slit experiment demonstrating the interference of single electrons. Why was this experiment considered the most beautiful? Some respondents identified aesthetic properties familiar from discussion of theory: the experiment was considered elegant and economical. For others, what was most crucial was the experiment's 'revolutionary' result and 'transformative power'. In this sense, the beauty of the experiment went hand in hand with its demonstrative force: the fact that seeing the experiment convinced many of the truth of quantum mechanics (2002, 20).

Yet the experiment was also evaluated aesthetically, and the way that interests us here, has to do with an idea that Crease labels "deep play". Part of the beauty of the double slit experiment is how 'the experiment stages a performance that does not just occur in nature, but unfolds only in a special situation setup by humans. In doing so, it dramatically reveals—before our very eyes—something more than what was put into it' (ibid.). Crease considers this 'deep play', because it is a case of 'being actively engaged with something outside ourselves that is responding to us'. This back-and-forth is contrasted with watching an event unfold that we have constructed in its entirety, or merely watching nature from a 'detached distance' (ibid., 19). Thus, in deep play, the scientist themself engages with, and observes the results of, experimental manipulation. In other words, they are an active participant of the experimental process. Part of what makes the double-slit experiment aesthetically valuable, then, isn't simply its elegance or the clarity of its results, but how it situates an agent vis-à-vis the experimental intervention.

"Deep play" can be connected to discussions of agency in experiments from philosophy and sociology of science, in particular, in the work of Karen Barad and Andrew Pickering. Barad's 'agential realism' emphasizes the dynamic interactions between scientists and experimental apparatus (2007). The experimenter, in designing, building and running experiments, actively generates divisions, measurements and forms of agency. For Barad, the objects of experimentation are not an independently existing part of the world, but rather emerge from scientists' actions. While we think that Barad is right to emphasize the active role of scientists in constructing their experimental apparatus, we think that taking the role of the world out of the equation goes somewhat too far, as we'll see.

Pickering also emphasizes the human-world interaction involved in experiments, arguing that it should be understood as a '*dance of agency* between the human and the non-human'. On this view, scientists have "active phases", where they are 'genuine agents, setting up their apparatus this way or that', and "passive phases", where they 'stand back and see what happens'. In the scientists' passive phases, nature itself is active; it is independent of human goals. This process then iteratively carries on, returning to the scientists' active phase: they respond to whatever happened, and then they see what happens again (2012, 318). As he notes, scientists often do not interact directly with their target system (the system that they are ultimately interested in learning about) but instead interact with an experimental object; the instruments and/or machines that generate data.

On Pickering's model, we can understand experimentation as involving two forms of agency acting in turn. Scientific agents setup experimental systems and prepare interventions, nature then takes over in the actual experimental run and, in light of those results, the scientist prepares further interventions. One might worry about predicating agency onto nature, but we can understand Pickering's central point without this commitment via insights from the philosophy of experiment. The epistemic powers of experiments turn on their results not being wholly controlled by the experimenter: if they are to test hypotheses and to potentially generate surprising results, experimental subjects must have a range of possible responses to experimental interventions. As Mary Morgan put it in the context of experiments in economics: '… new behaviour patterns, ones that surprise and at first confound the profession, are only possible if experimental subjects are given the freedom to behave other than expected by the experimenter-economist' (2005, 324).[1] Pickering's conception of nature's agency acting in experiments can be understood via this notion of 'freedom'; the experimenter's behavior is not itself sufficient to determine the experiment's results. Some aspects of the experiment are controlled by design: which specimens are used, how they are intervened on, etc., but (in the good case) the focal behavior of the specimens is not (hence Barad's account going, on our view, too far).

So, from Crease we get the idea of scientists' being actively engaged—as participants—in experiments, from Barad we get the idea that the experimenter actively generates forms of agency, and from Pickering we get the idea that this engagement is iteratively related to results from experiments. While Crease links his idea of "deep play" with the widely recognized beauty of the double slit experiment, we might be left asking: What has any of this to do with aesthetics? How does experimental design afford aesthetic agency in scientists? To see this, let's turn to a discussion of agency in contemporary aesthetics.

3. Experiments & Games

In *Games: Agency as Art*, Nguyen argues that games are a distinctive art form. Just as, say, painters use visual media, game designers, he argues, use agential media. On Nguyen's view, a game designer 'crafts for players a very particular form of struggle, and does so by crafting both a temporary practical agency for us to inhabit and a practical environment for us to struggle against' (2020, 17). Designers situate the agent within their construction, and forms of agency emerge as the temporary goals of gameplay (checkmate, scoring a basket, etc.) are taken on within the constraints of the game's rules.

Nguyen focuses on "Suitsian games", after Bernard Suit's (1978) analysis. These are games that involve practical struggles. One of Nguyen's examples is the role-playing game *Sign*, designed by Kathryn Hymes and Hakan Seyalioglu. In the game, each player is given an inner truth, known only to themselves. The goal of the game is to communicate this truth to the other players. Crucially, this truth must be expressed without speech and so, the players must invent a sign language over the course of the game. Nguyen argues that in order to experience the 'intense, absorbing, frustrating, and surprisingly emotional' nature of *Sign*, 'the players must commit, temporarily, to the goal of communicating their particular inner truths. And that commitment, combined with the particular rules of the game, leads to a very concentrated practical experience' (2020, 2). Furthermore, in cases of Suitsian games, game designers create

[1] For further discussion of Morgan's arguments, see Parke (2014), Currie (2018), Beisbart (2018) and French and Murphy (2021).

these practical environments with the view to provide players with an *aesthetic* experience of practicality. In *Sign,* players can have an aesthetic experience of their own action, the ways in which they try to effectively communicate their inner truth, in response to the prescribed boundaries of the game.

A feature that is useful for the comparison with experiments is that games are *artificial:* Games are constructed to shape the player's experience. Further, this artificiality allows the game designer to zero-in on the specific practical agency that they are interested in the players exploring. In *Sign*, players engage in generative communication, using combinations of facial expressions and gestures to slowly build up a catalogue of words. For Nguyen, the game's rules are basically a recipe for crystalizing that agency. Similarly, experiments are artificial setups with goals, aims and constraints which the scientists running them strive to abide by. Let's consider how Nguyen's account squares with experimentation.

The core connection between experiments and games concerns what Nguyen calls "constitutive constraints": the game's specific design parameters. In the case of Suitsian games, the constitutive constraints are the goals and the rules of the game. In *Sign,* we saw that the goal of the game is to communicate some inner truth, and one rule is that you are not allowed to talk. The specific goals of the game are generated in the interaction between goals and rules: without the constraint of silence, players could simply tell the others their inner-truth. They would not, then, be playing *Sign.* Paradigm experiments, we argue, also involve constitutive constraints: there are a set of rules that dictate how the apparatus should be setup. Further, there are specific measurements to be made and—at least sometimes—specific hypotheses to be tested. In principle, then, we might draw an initial analogy between games and experiments: both are goal-oriented and both have constitutive constraints. From this analogy we might draw another: just as game design situates players in order to experience certain forms of agency, so too does experimental design facilitate forms of agency in scientists. Thus, agency enters into science through experimental design. In running the experiment, the scientist takes on the temporary agency encoded in experimental design.

Before expanding on this basic idea, let us highlight some important differences between experiments and games: we're in the business of drawing analogies here, not claiming that experiments are games. The first difference concerns function. In the case of games, this is (often) enjoyment. By contrast, experiments (often) have epistemic goals: scientists conduct experiments in order to learn something about the world. No doubt there are many counterexamples to this claim: many games are more about pedagogy, or various forms of exploration, than fun; some experiments are also primarily pedagogical, and, while some games are experimental, some experiments take the forms of games. Regardless, *paradigmatically* the point of taking on the temporary agency of games is to have a good time in the struggle; while *paradigmatically* the point of the temporary agency encoded in experiments is epistemic, as we'll cash out below in our discussion of design.

A second difference concerns the source of constraints on practical environment. In game design, there are often physical constraints. For example, the particular controller used in a console game will affect the player's experience (Nguyen 2020, 16).[2] However, the core focus of Nguyen's account is the setting of rules by the designer. Similarly, in an experiment, there are constraints that come from experimental design. However, there are also constraints that come from the experimental object or specimen; the parts of the world that the scientist is trying to learn about. The setup of the double-slit experiment, for example, comprises the scientific agent and their experimental apparatus (the "slits", for example), but also the particles themselves. In Pickering's terms, this is where nature itself becomes "active". We can therefore see that a crucial difference between games and experiments is that where in games there are only players and constraints, in experiments there are the scientists, the experimental constraints, and the world. In a more Pickering-esque vein, we could conceptualize the world itself as another player. Regardless of how we label these three features, we want to emphasise the following: because experimenters are interested in determining how some part of the world—the specimen—behaves under various controlled conditions, there is a third element beyond the scientific agent's and the experiment's constraints: the specimens themselves.[3]

A distinction that is important for Nguyen's analysis and also relevant for our aims here is between the game designer and the game participant. While the designer of the game can also participate in the play, the focus of his book concerns how designers design games to constrain other players' activity. In the case of experiments, we can also make a distinction between those who design experiments and those who run them, i.e., cases where the original designer of an experiment has designed the experiment, refined it, and the method is then passed on for others to conduct the experiment. This could include cases where lab technicians run an already-designed experiment, in the context of pedagogy where students perform an experiment for themselves in order to experience the experimental phenomena, or (perhaps more controversially[4]) when different labs attempt to replicate results. Perhaps these are the cases in which Nguyen's analysis most naturally applies: we have the designer of an experiment who passes on its "rules", and in doing so, shapes the participants' experience in ways that allows for an aesthetic experience of their own agency.

However, as with games, sometimes the designer and the person who runs the experiment will be the same. We are also interested in the agency of those who construct and design experiments, and therefore, not just in complete experiments but also their initial development. David Gooding (1992; 2001) argues that the processual side of experiments is often overlooked in philosophy of science because experiments tend to be represented retrospectively (both by philosophers of science, and in scientific papers themselves) in terms of their outcomes. This results in the agency of experimenters being left out of the narrative. A focus on agency in science, then, can allow us to think about an aesthetics of experiments that goes beyond the product of experimental design to incorporate processes as well.

[2] See also Kirkpatrick (2011, chapter 3) for an argument for how the physicality and limitations of a hand-held controller is a central part of our aesthetic appreciation of video games.

[3] We anticipate there are many games where the world acts as a third player: take for instance rock climbing, one of Nguyen's favourites. In outdoor rock climbing, at least, the physical constraints, surprises, and contingencies of the natural formations themselves play a crucial role in shaping the agency of the climb. We leave how crucial this point is for further examination.

[4] For discussion of the so-called 'replication crisis' see (e.g., Guttinger, 2019; Nelson *et al*, 2022).

Caveats regarding aim and constraints aside, the analogy between games and experiments that we have drawn allows us to claim not only that experiments produce particular experimental results (measurements, data, etc.), but also that their constitutive constraints produce agency in the scientists running the experiments. But what kind of agency and to what purpose? This leads us to a discussion of design.

4. An Aesthetics of Experimental Agency

So far, we have seen that switching our focus from theories to experiments highlights different aesthetic properties. The aesthetic analysis of theories brings out formal qualities: simplicity, elegance, symmetry and so on. But experiments are processes that generate results, and so, the shift to experiments opens the way for a consideration of the aesthetic properties of those processes and their outcomes.

Ivanova (2022) points to the connection between elements of design and the intended output of an experiment. One aspect of the beauty of, say, the double slit experiment, is that it clearly confronts us with its results. The experimental phenomena—the surprising, confounding patterns the particles leave after shooting through the slits—is distinctly captured by the experimental setup. One might at this stage be tempted to say that herein lies another difference between games and experiments. In games, good design is understood in terms of how it effects the agency of the players, whereas good design in experiments is understood in terms of the experimental result (say, whether it cleanly decides between two hypotheses). While experiments can be appreciated in this way, we will explore denying that this is all there is to aesthetics of experiments. That is, can good design in experiments also be understood in terms of scientists' agency?

In this section, we'll provide an account of the aesthetic agency of experiments in three steps. First, we'll briefly consider the relationship between agency and how experiments are designed. Second, we'll dive—with some detail—into a case-study, namely Newton's optical experiments. Third, we'll use the case to explain how design and agency come together in experiments to generate important aesthetic properties.

4.1 Experimental Agency & Design

How does experimental design afford scientific agency? Consider the experience of a scientist performing an experiment: there are certain aspects of the process that they attend to, and others that are less important. Like artworks, they have a "prescriptive frame" as Nguyen puts it in the context of games:

> Games share with traditional artworks a prescriptive frame. That means that, in order to experience the artwork, you have to follow certain prescriptions about how you will confront it. You must attend to the work in a prescribed way in order to experience the work. (Nguyen 2020, 121)

Experimental procedures require particular behaviour from scientists: observing, measuring, pouring, stirring, twisting dials, positioning, watering, incising, collating, cleaning, and so on. Moreover, across different experiments different features are relevant and crucial. An art gallery encourages certain prescriptive frames (observing the art from particular distances at particular angles, attending to the painting rather than the blank walls between them, and so forth) towards highlighting the relevant parts of the artwork. Similarly, lab contexts and experimental procedures involve prescriptive frames which organize scientific activity towards producing relevant results. In experimental design, scientists do not simply specify a set of apparatus and operations, but a prescriptive frame. In the double-slit experiment, what is crucial is the relationship between the expected array of electrons and the actual array of electrons. When double-checking the experiment's setup, we might concern ourselves with the exact positions of the slits, and so forth. But in performing and experiencing the experiment, that crucial expectation-versus-outcome relationship takes centre stage.

Through such design properties and the prescriptive frame, we see a form of agency emerging, analogous to the agency we find in games. However, what in this context would make for *good* experimental design? Ivanova has highlighted the relationship between experimental design and the experiment's results: to continue with our example, the double-slit provides a precise demonstration of a crucial phenomenon underwriting quantum mechanics. We take ourselves to have also suggested that forms of experimental agency arise. What is the purpose, function and nature of this agency, and how does it relate to design? In the simplest experimental contexts, we might say that the scientific activity is directed towards the scientific agent *experiencing the experimental phenomenon*. But as we'll shortly demonstrate, there are crucial aesthetic components to such agency. In the following section, we'll explore these ideas in more depth by way of a case study: Newton's optical experiments.

4.2 Newton's Optical Experiments

In Book 1 of his *Opticks*, Newton employs what he terms "proof by experiments". For most theorems in this book, he presents a sequence of experiments that is supposed to constitute a single proof for the proposition. Each experiment reveals some property of light and, taken together, the experiments are supposed to establish the truth of the theorem. Consider Part 1 Proposition 2 Theorem 2 (hereafter referred to as "Proposition 2"). This states that '*The Light of the Sun consists of Rays differently Refrangible*' (Newton 1952, 26), where "refrangibility" refers to the disposition of light to refract when passing from one medium into another. The proof for Proposition 2 comprises a sequence of eight experiments: Experiments 3 to 10 in Book 1 Part 1. The probative force of this sequence isn't what concerns us here, so we will just look at the first two experiments in the sequence to explore how good experimental design can be understood in terms of scientists' agency. We will start by describing the experiments, before highlighting several relevant features.

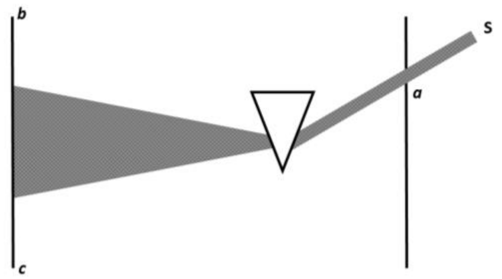

Figure 1: Experiment 3

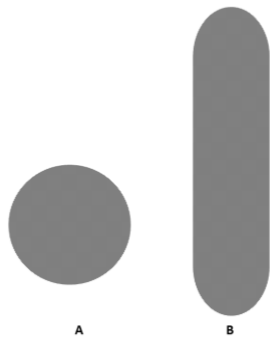

Figure 2: Expected (A) and actual (B) results of Experiment 3

In experiment 3, Newton describes the experiment represented in figure 1, where there is a hole in the window shutter (*a*), through which a narrow beam of sunlight (*S*) enters the room, and that beam of sunlight is projected through a triangular prism onto the screen (*bc*). His main concern in this experiment is with the image on the screen. He explains that, according to the received laws of optics, under the conditions of this experiment, refraction should have been equal. And so, the image at *bc* should have been circular. However, the image is observed to be oblong (B, rather than A, in figure 2). Newton writes:

> And therefore seeing by Experience it is found that the Image is not round, but about five times longer than broad, the Rays which going to the upper end [*b*] of the Image suffer the greatest Refraction, must be more refrangible than those which go to the lower end [*c*], unless the Inequality of Refraction be casual. (Newton 1952, 32)

In other words, experiment 3 demonstrates that some rays have been refracted more than other rays, causing them to land higher on the screen than rays that are less refracted. And so, refraction is unequal.

In experiment 4, Newton keeps his prism in the same position, but instead of focusing on the projected image at *bc*, he shifts his attention to the aperture *a* in the window shutter, observing it through the prism. In the previous experiment, the image appeared oblong rather than circular, similarly, in this experiment, the aperture looks elongated when viewed through the prism.

As noted above, Newton's proof by experiments for Proposition 2 includes six other experiments, but these two (experiments 3 and 4) are enough to illustrate several key points.

First, there are many observables that Newton *qua* experimenter ignores. For example, while these experiments produce a colour spectrum out of white light, Newton doesn't talk about colour in his descriptions but instead focuses on the geometrical features, namely, the angles of incidence and refraction, the size and shape of the image on the far screen, and the size and shape of the aperture.[5] This is significant because, by limiting the description to certain

[5] For discussion of this point in its historical context, see (Walsh 2017a).

features, Newton is controlling the prescriptive framework—telling his readers which aspects of the experiment to attend to. This defines and clarifies the scope of the experimental phenomenon, identifying precisely which aspects of the experiment are relevant to the experience.

In this case, attending to geometrical features is crucial since these features make the phenomenon measurable and allow the phenomenon to become evidence for Proposition 2. The point here is that these experiments need to be engaged with in a certain way, if the experimental agent is to both experience the phenomenon and measure it. This means that experimental robustness does not simply turn on the experimental apparatus delivering the right result, but on the scientists participating in the right way.

A second thing to notice is that Newton *qua* experimenter is part of the experimental setup. Most obviously, this is demonstrated by the fact that he must position himself differently in each experiment in order to have the relevant experience. In experiment 3, he must be positioned such that he has a direct and unmediated view of the screen *bc*. To ensure that he does not block the light from reaching *bc*, he must be positioned slightly to one side of the light source. In contrast, in experiment 4, he must turn to face the aperture *a*, and position himself so that he can observe *a* through the prism. In short, the experimental result is dependent on the observer's experience, which in turn, is dependent on their positioning as the observer.

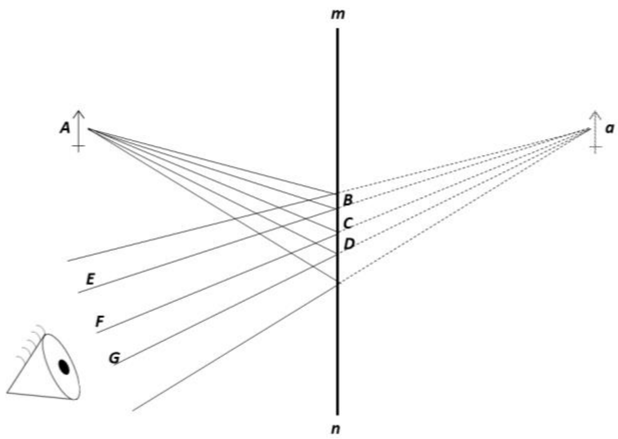

Figure 3: Axiom 8 demonstrated for reflection

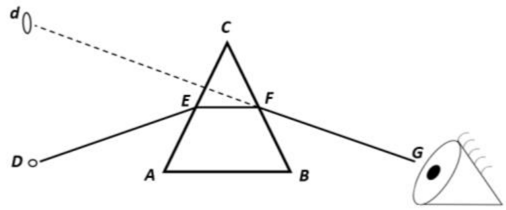

Figure 4: Axiom 8 demonstrated for refraction

This is no accident: the relevance of the observer's perspective is encoded in the axiomatic framework of the inquiry.[6] For example, Axiom 8 states that '*An Object seen by Reflexion or Refraction, appears in that place from whence the Rays after their last Reflexion or Refraction diverge in falling on the Spectator's Eye*' (Newton 1952, 18). Newton demonstrates this point in several ways. For example (see figure 3), he demonstrates that an object *A* observed by

[6] The axioms are listed at the beginning of Book 1, after the Definitions and before Proposition 1.

reflection in a mirror *mn* will appear, not at its actual place *A*, but behind the mirror at *a*. He also (see figure 4) demonstrates that an aperture *D* observed through a prism *ABC* will appear at *d*.

Further, in Newton's experiments, the experimenter might be considered part of the experiment in perhaps more mundane ways. For example, he must manipulate the prism, turning it on its axis and positioning it so that it may capture and project the sunlight in the right way. Similar adjustments must be made to the screen and, in later experiments, mirrors, threads and pages of text. In this sense, he interacts with the light, albeit indirectly, via the experimental apparatus. Experiments 3 and 4 are more or less static, in the sense that the experimental setup and the resulting phenomenon are fixed for the length of the experiment. But later experiments in the sequence are much more dynamic, requiring the experimenter to rotate a prism, or manipulate a mirror or screen, during the experiment. In each of these cases, the experimenter experiences mediated interaction with the light, and hence becomes part of the experimental setup.

A third thing to notice about Newton's experiments is that experiment 3 is what we might think of as a "core experiment". Newton describes a single experiment, the parameters of which are adjusted over the series of eight experiments (including experiment 4, as we have seen).[7] The value of this feature lies, in part, in the open-endedness of this sequence—both for Newton and his readers. Over the course of Book 1, Newton goes through numerous variations of this core experiment.[8] Moreover, the way Newton describes these experiments gives his readers enough information to replicate the experimental sequence,[9] beginning with experiment 3, and then to generate even more new experiments of their own.[10] In other words, Newton intends that these experiments will be enacted, rather than merely read or "virtually witnessed".[11]

There are multiple ways in which Newton's optical experiments can be said to have aesthetic value. Most obviously, there is the sense in which, in his early optical work, he described his experience of 'the celebrated *Phænomena* of *Colours*' as 'a very pleasing divertisement, to view the vivid and intense colours produced thereby' (Newton, 1959-1977: Vol. 1, 92). But it is clear that Newton takes the experiments themselves to have value in terms of their simplicity, the way they efficiently and effectively display optical phenomena, the way they facilitate

[7] We borrow the term "core experiment" from Dana Jalobeanu, who introduces the term to describe an important characteristic of Bacon's natural histories. She writes, 'these natural histories … seem to have been put together from a relatively limited number of experiments from which Bacon generates, through experimental variation, new cases, observations and "facts". In fact, one can identify in the Latin natural histories a number of experiments from which facts and results are so generated. I will call such experiments "core experiments"' (Jalobeanu 2011, 92). We use the term here in the same way.

[8] Arguably, the variations are countless, since it is often not entirely clear which adjustments to the experimental parameters count as, in some sense, discrete variations.

[9] As Jalobeanu has noted, in good Baconian form, Newton's instructions were 'detailed enough for the reader to attempt to replicate [the experiments], but not precise enough to make replication trivial' (Jalobeanu 2014, 57).

[10] Indeed, the first time Newton described his core experiment in print (Newton 1672), it inspired many natural historians and philosophers to conduct prism experiments. For example, Robert Moray generated experiments on Newton's new theory in this way (Moray 1672).

[11] "Virtual witnessing" is a term coined by Steven Shapin and Simon Schaffer (Shapin 2011, 60-65). Virtual witnessing is understood as using language to convey the experiment in such a way that the reader feels as though they have experienced it. It produces a vicarious experience, which enables the reader to confer agreement. We think our account allows us to distinguish between the embodied way one experiences the phenomenon when enacting an experiment for themselves and the kind of vicarious experience described by Shapin and Shaffer. We discuss this in section 6.

exploration and discovery of optical phenomena, and the way they compel experimenters to assent to Newton's theoretical propositions. These values have much to do with good experimental design, in the sense described by Ivanova (2022). But in this paper, we are interested in the relationship between aesthetics and agency in scientific experiments, and we think Newton's experiments offer insight about this as well. This is what we will focus on in the next section.

4.3 Insights from Newton's Optical Experiments

In this section we explore the insights offered by our discussion of Newton's experiments on the relationship between aesthetics and agency in scientific experiments. We glean at least three insights.

Our first insight is that experiments have a 'prescriptive frame'. Above, we noted that, in his descriptions, Newton instructed his readers to focus on some aspects of the experiment and to ignore others. This controlled their experience of the phenomenon and allowed the experimental result to function as evidence for Proposition 2. As we've seen, having a prescriptive frame is a feature Newton's experiments share with games, and also with artworks. In short, both experiments and art have to be engaged with in the right way, if the agent is to have the intended experience, and hence, observe the phenomenon in the right way.

Further, prescriptive frames are crucial for experiential intersubjectivity: insofar as different individual scientists take up the same constraints and activities, there is a continuity across them regarding that agency. Nguyen makes precisely this point regarding games. He writes:

> … certain kinds of prescriptive structure help to stabilize our experiences, and make them, to a limited extent, sharable. That stability makes it possible for the designer to sculpt a particular kind of activity and pass it to the player—and so to help shape the player's aesthetic experience of their own agency. (Nguyen 2020, 122)

In the case of scientific experiments, this intersubjectivity is what allows experimental phenomena to become stable sources of evidence for theoretical claims.

Our second insight is that experimenters develop embodied skills. Above, we noticed that Newton's experiments require an active experimenter to manipulate the apparatus (including their own bodies). Newton rarely provides precise instructions for how to position and manipulate the apparatus. As we noted above, this is best understood in terms of the Baconian strategy of providing enough instruction to make replication possible but nontrivial. In the Baconian tradition, a reader would enact an experiment, not simply to verify the evidence for themself, but to grasp the phenomenon on a deeper level—replication was supposed to be a productive exercise for the mind.[12] Moreover, by figuring out how to twist and tweak their apparatus and body in order to obtain a clearer view of the image, the experimenter would develop embodied skills.[13]

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[12] Jalobeanu explores this notion of the Baconian method employed by the early Royal Society as "a Therapeutic of Experimentation" in (Jalobeanu 2015, ch. 3; see also Jalobeanu 2014, 51-56)

[13] The importance of embodied skill for Bacon's project can be seen in the way he accorded craftwork (i.e. the technical skills and craft practices of artisans and mechanics) a central place in his natural philosophy (e.g. Bacon 2000, 64). For discussion, see (Pérez-Ramos 1988; Weeks 2008; Young 2017).

This aspect of experimentation is often captured in discussions of 'know-how', 'tacit knowledge' and 'tribal knowledge', but such discussions tend to focus on the outcomes of experiments, in their finalized form. Here, we are interested in embodied skills in the process of experimentation. Gooding similarly emphasises the embodied skill of the experimenter. On our view, the development and use of such skills can be seen as part of the prescribed kinds of scientific engagement required for the conduct of an experiment. As Nguyen highlights in his discussion of games, the practical obstacles that participants of a Suitsian game must overcome are not always just obstacles for the mind. Rather, there can be physical obstacles too. Take the case of rock climbing in which climbers must find the right ways to move their bodies in order to complete a route (Nguyen 2020, 12). In section 3, we noted that philosophers of science tend to look at experiments in their finalised form, rather than seeing them as a process. Gooding argues that this has led to an important feature of experiments being ignored, namely, how embodiment is central to the stabilization of experimental results (1992; 2001). As seen in Newton's experiments, the constitutive constraints are not just the apparatus and the "rules"—the design of the experiment—but also nature, i.e., specimens and their behaviour. Part of the process of getting an experiment to work is getting the specimen to interact with the apparatus in the right kind of way. This often relies on embodied skill.

Our third insight is that, in designing an experiment, a scientist can provide opportunity for aesthetic experience of their own agency as well as give others who conduct it the opportunity to have such an experience. This highlights the close relationship between good experimental design and the experimental agent. Scientists learn new forms of agency intimately connected with experimental phenomena thanks to the constitutive constraints of experiments. Successfully performing Newton's experiments is no minor feat, requiring much playing around—deep play—with apertures, prisms, and such like.[14] In so doing, working within the prescriptive frame and constitutive constraints encodes the agency of this kind of experiment and affords the capacity of scientists to express their own agency within that experimental paradigm.

That experiments generate particular forms of agency allows us, further, to draw a contrast between those who merely witness the experimental phenomena (say, the Fellows of the Royal Society who watched Robert Hooke perform these experiments at their regular meetings)[15] and Newton, Hooke and others who actually performed the experiments. The latter experience a practical struggle that the former do not. Nguyen's notion of "practical harmony" offers some machinery to help articulate this.

To get clearer on the *aesthetic* in his aesthetics of agency, Nguyen discusses three kinds of practical harmony. The first, the "harmony of solution", involves harmony between a particular obstacle and the solution to address that obstacle. He contrasts this with a second kind, the "harmony of action":

[14] Similarly, take the incredibly advanced technology and skill required to conduct the double slit experiment with single electrons. Given the complexity of the setup required, Feynman thought the experiment would only be able to be performed as a thought experiment, rather than materially (Feynman 1965, chapter 1). The way in which difficulty affects the aesthetic experience of one's agency is fleshed out below in terms of Nguyen's notion of "practical harmony".

[15] See, e.g. (Birch 1757)

> When you time a jump just so in *Super Mario Brothers*; or when you figure out, during a rock climb, that you need to slide your hips over just enough to balance on that tiny nubbin of rock, you're experiencing more than the harmony of solution. You're experiencing your agency and action as fitting the demands of the environment. You experience, not only the fit between the obstacle and the solution, but the fit between the obstacle and yourself as the originator of those solutions. (2020, 108)

The harmony of solution is something that both a spectator of a game and the player themselves can have access to. However, the player has special access to the harmony of action: 'After all, they came up with the move themselves; they chose a course of action. They know what it feels like to analyze the situation, to find the solution, to react with precision and grace, and to have inspiration strike' (2020, 108). The harmony of action involves not only a solution that addresses some problem but rather a feeling of 'how my decision-making and action-generation were just right to generate that fitting solution' (ibid.).

A third kind of practical harmony that Nguyen presents is "the harmony of capacity". This goes beyond both harmony of solution and harmony of action, it is 'particular to the experience of doing difficult things—of engaging your abilities fully. The harmony of capacity arises from a fit between one's maximum skill level and the demands of the task. It is only available when you are pushed to your limit' (2020, 109). For Nguyen, this is the most profound and aesthetically rewarding type of practical harmony and he considers it far rarer that the other two types. It's a 'sense that one's abilities are working perfectly in tune and performing actions right at the limits of one's capacities … it offers us a feeling of fitting the world, practically speaking' (ibid., 110).

Returning to the Fellows of the Royal Society who merely witnessed Newton's experiments, we might say that only harmony of solution is accessible to them. They can appreciate the fit between problem and solution without going through the process of trying to produce the experiment for themselves. In contrast, Newton, Hooke and other keen and successful replicators gain access to the harmony of action by actually doing rather than just spectating, and this is both epistemically and aesthetically rewarding. Harmony of capacity might be accessed in cases where isolating a phenomenon involves a huge amount of precision and skill, or by those who don't simply replicate but come up with new variations. In early modern experimental philosophy, which took a broadly Baconian form, the value of an experiment doesn't lie just in what is revealed or demonstrated by that particular experiment, but in the way it affords agency by inspiring variations. Individuals enact their agency by manipulating prisms and rays of light—not merely replicating Newton's experiments but creating new conditions under which to observe the phenomena. Again, then, this chimes with Nguyen's discussion of games. While Newton presents "rules" of the experiment and there are other constitutive constraints that come from the apparatus (the prism) and the specimen (the beam of sunlight), these do not fully dictate the practical environment: Newton's readers have freedom of action within this practical environment.

Finally, what can we say about good design in experiments? Well for Newton, a well-designed experiment doesn't merely test hypotheses, rather, it offers an especially illuminating experience of the phenomenon, and affords "compelled assent".[16] In other words, we miss something crucial when we overlook the aesthetic experience of the agent in our analyses of these experiments.

Drawing on this extended discussion, the following view on the nature of experiments, agency and aesthetics can be articulated. Experiments, via prescriptive frames and constitutive constraints, generate a form of agency which scientists (both in designing and performing the experiment, depending on context) learn about and engage in. What makes for good experimental design in this instance is not simply the clarity of the match between result and hypothesis, for instance, but in how that design generates forms of agency. From the above, here is an initial list of how an experiment may be *agentially* beautiful:

(1) Directness: the experimental participant has an experience of the experimental phenomenon; (2) *stability* and *sharability*: the prescriptive frame affords intersubjectivity of experience; (3) *embodiment*: the experimental design and description encultures the use of particular skills in participants; (4) *deep play*: the scientific agent is able to exercise their own agency within the constraints of the experiment; (5) *harmony of action and capacity*: performing the experiment goes beyond mere witnessing.

This is an initial, partial list, we are sure—hopefully downstream, further work will refine, critique and clarify it. Regardless, we take ourselves to have shown that an aesthetics of experimental agency is crucial to understanding experiments. We want to close with a more critical discussion which focuses on the first feature in our list: directness.

5. Experimental Distance

We have thus far argued that scientific agency can be understood in terms of the agency that emerges from the constitutive constraints of experimental design: the procedures and apparatus of experimentation. We've suggested that this agency is critical for scientific knowledge due to providing intimate knowledge of experimental phenomena, further highlighting a set of sources of aesthetic value in science. In this section, we want to preempt a possible objection to our view which is rooted in the fact that in many scientific experiments, there is *distance* between the scientist conducting the experiment and the experimental phenomena. We will outline two different ways in which this distance is realized, before presenting some responses to this worry that also indicate future directions for accounts of aesthetic values in science.

As we saw in section 1, Crease claimed that part of the beauty of the double-slit experiment was that it involved "deep play"; namely, a scientists' construction of a "special situation" that "reveals something before our very eyes". This seems to speak to experiments as they are imagined: a lone scientist manipulating a relatively simple apparatus to generate a clear result. Here, there is a direct engagement between the scientist and the experimental phenomenon,

[16] For an account of Newton's notion of certainty as "compelled assent", see (Walsh 2017b, 876-877).

and our discussion of agency seems to apply quite straightforwardly. The same goes for our example of Newton's optical experiments as discussed in the previous section.

But most experiments are not like this. Consider a simple botanical experiment: the scientist is interested in the effects of different soils on the growth of a plant. So, they place specimens into different soils and measure them over a long time. They may observe that some plants are growing faster, or further, than the others, but these casual observations are not critical: what matters is the quantified measurements and statistical relations that are uncovered between plant growth and soil type. It would be odd to suggest that experimental phenomena are observed or experienced in these contexts, rather they emerge from data analysis. There is 'experimental distance' between the phenomenon and scientific agent.

Big Science provides the clearest examples of this. Research projects such as the Large Hadron Collider or the Event Horizon Telescope involve large numbers of scientists, each bringing different expertise, and often placed in different locations, coordinating to conduct collective research. Ivanova discusses how experimental practice has changed over time, highlighting the differences between seventeenth-century experiments compared to contemporary large-scale ones. She indicates that this might impact how they are evaluated aesthetically given that the experiment's results in the latter case are not immediately perceived. Despite this, she argues that a 'central aspect of appreciation remains how well the experiment is designed for purpose and whether it is optimal' (2022, 10). While Ivanova's account may easily be able to accommodate such cases, things might be more difficult for a view that points to an aesthetics of agency in science. Again this is due to experimental distance: although individual agents might experience some aspect of the experiment, no one individual can observe the experimental phenomenon. The same problem arises when we consider the increasingly automated nature of science, (Holland & Davies 2020) in which human agency is removed from many or all aspects of the conduct of an experiment beyond their design.

We can understand *experimental distance*, then, in terms of how accessible the experimental phenomenon is to the experience of the scientists running the experiment. Although in some cases there seems to be a fairly direct relationship between experimental phenomena and the scientist's agency—the experiment well-places the scientist to experience the phenomenon—these cases are vanishingly few and certainly do not track large-scale, industrialized science. Do such cases lack an aesthetic component, or do they undermine an aesthetics of agency applied to science? Can they be accommodated by our account? There are many possible responses to this worry.

It might be that we have identified something which is lost when science "goes big", i.e., when there is great distance between the experimenter and the experimental phenomenon. It is clear that large experiments have much to offer by way of gains, but perhaps they lose something important: the embodied aesthetic agency of the scientist. And so, perhaps the scope of some of our points is limited to experiments such as those discussed in section 4. However, we suspect that many of the aspects highlighted above (shareability of experience, harmony, etc.) might be possible even if the agent's experience is very far from the phenomenon itself.

Furthermore, we can highlight how an experience of one's agency has an important function in the context of pedagogy. As mentioned, Nguyen's analysis of games applies fairly straightforwardly to instances in which an experiment has already been designed and is "fixed" in some sense, and then students conduct these well-established experiments for themselves. In these cases, the aim is not to discover something new, but to gain an understanding of some theory or the phenomenon that the experiment produces. There is a clear pedagogical benefit in students being able to perform an experiment for themselves—trying out different solutions, choosing a course of action and seeing the experimental phenomenon change as a result. Pedagogy is important, as is thinking about how scientists become scientists. There might be something, then, to limiting our account to such cases.

Another response points out that the notion of experimental distance has some interesting properties, potentially providing a basis for thinking comparatively about different experiments, differences that might matter for good design. Some experiments, such as classical optical and mechanical experiments, and the double-slit experiment, involve a fairly direct relationship between experiment and experimenter's experience, while others do not. As distance increases, scientists no longer experience the phenomenon itself. Recognizing these differences in various experiments does not mean that scientists' agency is unimportant in cases of experimental distance.

In our discussion above, we emphasized the proceduralism of experiments: experiments should not be thought of only in terms of results, but in terms of procedures. Embedded in such procedures the agent might not experience the phenomenon, but rather partial aspects of the experimental process. In running an experiment, many monitoring activities are required, getting a sense of whether things are proceeding properly. That kind of agency is plausibly critical for understanding the experiment. Further, there is a lot of agency in data analysis—it's not merely automatic nor disengaged. The intuitive analogy between games and experiments looks murkier here, but if we want to say that well-designed experiments well-place scientific agents to understand the relationship between their agency and (to draw on Pickering) "the world's", perhaps understanding the analysis of experimental results in terms of agency is also called for.

Finally, perhaps there is a space for thinking about "distributed agency" or "distributed aesthetics" in understanding experiments. Many philosophers of science commit to some form of social epistemology, where the locus of scientific knowledge is understood to be in scientific groups, communities and collective practices, rather than in individual scientists. At first blush, this might sit awkwardly with the apparent individualism of this discussion of individual scientific agencies. But recalling our discussion of the "shareability" of scientific agency, this tension might be less than it originally seemed. It is not simply in how scientific communities marshal collective epistemic activities but in how they situate the agency of various actors that science does its social epistemological work. In Nguyen's analysis of games as the art of agency, he highlights how the harmony of action is not limited to players as individuals. Instead, with reference to team sports such as basketball, Nguyen discusses how we can have 'a sense of your actions and abilities as fitting with those of other players, and of those collective actions as fitting the challenges of the game' (2020, 108).

And so, although agential distance *prima facie* seems to limit the scope of our discussion of the aesthetics of experiments, we see it as a jumping-off point for further discussion of the aesthetics of data analysis, partial experimental procedures, scientific collaboration and distributed aesthetics.

6. Conclusion

We have argued that a shift from properties of theories or experimental outcomes in an account of aesthetic value in science opens the door to thinking about the agency of experiments. Via Nguyen's work we have drawn an analogy between the art of games and scientific experiments in order to conceive of experimental runs and the process of experimental design in terms of the aesthetic experiences of scientific agents. We have taken Newton's optical experiments with prisms as a central case to illustrate this idea, which involve the agent positioning beams of lights through prisms and observing the different tendencies of the light to bend. This both affords the capacity to measure the light's refraction, but also to experience the phenomenon. The scientist enacts their agency through shifting the prism, manipulating the light and so on. Further, they take on an embodied form of agency afforded by the apparatus and the "rules" of the experiment.

We ended by considering a potential worry for our account: in the vast majority of experiments, there is a distance between experimental phenomena, experimental runs, and the (aesthetic) agential experiences of individual scientists. If we are to understand the aesthetics of experiments at least in part as an aesthetics of agency, then this challenge needs to be overcome, or we have to accept that the view developed here only applies to a small range of cases. While we accept that this is an issue, and we are committed to the idea that there are various ways in which experiments can have aesthetic value beyond the view we have outlined here, we have also sketched out various ways in which this problem might be overcome. This, we hope, indicates how centering agency in experiments opens new lines of enquiry for accounts of aesthetic values in science.

References

Bacon, F. (2000), 'The Advancement of Learning'. In M. Kiernan (ed), *The Oxford Francis Bacon, Volume 4,* Oxford, Clarendon Press.

Barad, K. (2007), *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning,* Duke University Press.

Beisbart, C. (2018), 'Are computer simulations experiments? And if not, how are they related to each other?' *European Journal for Philosophy of Science, 8*(2), 171–204.

Birch, T. (1757), *The History of the Royal Society of London, Vol. III*, London, Printed for A. Millar in the Strand.

Crease, R. (2002), 'The Most Beautiful Experiment', *Physics World* 15, no. 9.

Currie, A. (forthcoming), ‘Epistemic Engagement, Aesthetic Value & Scientific Practice’, *British Journal for the Philosophy of Science.*

Currie, A. (2018), ‘The Argument from Surprise’, *Canadian Journal of Philosophy, 48*(5), 639–661.

Feynman, R. (1965/2010). *The Feynman Lectures on Physics, Volume III: Quantum Mechanics.* Basic Books.

French, S. and A. Murphy (2021), ‘The Value of Surprise in Science’, *Erkenntnis.*

Gooding, D. (1992), ‘Putting Agency Back into Experiment’, A. Pickering (eds.), *Science and Practice and Culture.* The University of Chicago Press.

Gooding, D. (2001), ‘Experiment as an Instrument of Innovation: Experience and Embodied Thought’, *CT '01: Proceedings of the 4th International Conference on Cognitive Technology: Instruments of Mind.*

Guttinger, S. (2019). ‘A New Account of Replication in the Experimental Life Sciences’, *Philosophy of Science, 86*(3), 453-471.

Holland, I., & Davies, J. A. (2020). ‘Automation in the life science research laboratory’, *Frontiers in Bioengineering and Biotechnology, 8*, 571777.

Ivanova, M. (2021). ‘The aesthetics of scientific experiments’, *Philosophy Compass, 16(3)*, e12730.

Ivanova, M. (2022), ‘What is a Beautiful Experiment?’, *Erkenntnis.*

Jalobeanu, D. (2011), ‘Core Experiments, Natural Histories and the Art of *Experientia Literata*: the Meaning of Baconian Experimentation’, *Society and Politics*, *5*, 88-103.

Jalobeanu, D. (2014), ‘Constructing natural historical facts: Baconian natural history in Newton's first paper on light and colours’. In Z. Biener and E. Schliesser (ed), *Newton and Empiricism*, Oxford, Oxford University Press, 39-65.

Jalobeanu, D. (2015), *The Art of Experimental Natural History: Francis Bacon in Context*, Bucharest, Zeta Books.

Kirkpatrick, G. (2011). *Aesthetic Theory and the Video Game.* Manchester University Press.

Morgan, Mary. S. (2005), ‘Experiments versus models: New phenomena, inference and surprise’, *Journal of Economic Methodology, 12*(2), 317–329.

Moray, R. (1672), ‘Some Experiments Propos’d in Relation to Mr. Newtons Theory of Light, Printed in Numb. 80; Together with the Observations Made Thereupon by the Author of That Theory; Communicated in a Letter of His from Cambridge, April 13. 1672’, *Philosophical Transactions*, *7*, 4059-4062.

Murphy, A. (2020), ‘The Aesthetic and Literary Qualities of Scientific Thought Experiments’, M. Ivanova and S. French (eds.) *Aesthetics of Science: Beauty, Imagination and Understanding,* Routledge.

Nelson, N. C., Chung, J., Ichikawa, K., & Malik, M. M. (2022). ‘Psychology Exceptionalism and the Multiple Discovery of the Replication Crisis’, *Review of General Psychology*, *26*(2), 184–198.

Newton, I. (1672), ‘A Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; Containing His New Theory about Light and Colors: Sent by the Author to the Publisher from Cambridge, Febr. 6. 1671/72; In Order to be Communicated to the R. Society’, *Philosophical Transactions*, *6*, 3075-3087.

Newton, I. (1952), *Opticks: Or a Treatise of the Reflections, Refractions, Inflections & Colours of Light*, Dover Publications, Inc.

Newton, I. (1959-1977), *The Correspondence of Isaac Newton, 7 Volumes*. H. W. Turnbull, J. F. Scott, A. R. Hall and L. Tilling (ed). Cambridge, Published for the Royal Society at the University Press.

Nguyen, C. T. (2020), *Games: Agency as Art,* Oxford University Press.

Parke, E. (2014), ‘Experiments, simulations, and epistemic privilege’, *Philosophy of Science, 81*(4), 516–536.

Parsons, G. G., and A. Rueger (2000), ‘The Epistemic Significance of Appreciating Experiments Aesthetically’, *British Journal of Aesthetics* 40, no. 4: 407–423.

Pérez-Ramos, A. (1988), *Francis Bacon's Idea of Science and the Makers Knowledge Tradition*, New York, Oxford University Press.

Pickering, A. (2012), ‘The Robustness of Science and the Dance of Agency’, in L. Soler, E. Trizio, T. Nickles and W. Wimsatt (eds.), *Characterizing the Robustness of Science: After the Practice Turn in Philosophy of Science.* Dordrecht: Springer.

Turner, D. (2019), *Paleoaesthetics and the Practice of Paleontology,* Cambridge University Press.

Shapin, S. and Schaffer, S. (2011), *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*, Princeton University Press.

Suits, B. (1978), 2014. *The Grasshopper: Games, Life and Utopia*, *3rd ed*. Peterborough, CAN: Broadview Press.

Walsh, K. (2017a), ‘How Many Colours?’. In M. Silva (ed), *How Colours Matter for Philosophy,* Springer, 47-71.

Walsh, K. (2017b), ‘Newton: from certainty to probability?’, *Philosophy of Science*, *84*, 866-878.

Weeks, S. (2008), 'The Role of Mechanics in Francis Bacon's *Great Instauration*'. In C. Zittel, G. Engel, R. Nanni and N. C. Karafyllis (ed), *Philosophies of Technology: Francis Bacon and his Contemporaries,* Netherlands, Koninklijke Brill, 133-196.

Wragge Morley, A. (2020), *Aesthetic Science: Representing Nature in the Royal Society of London, 1650-1720,* The University of Chicago Press.

Young, M. T. (2017), 'Manual Labor and "Mean Mechanicks": Bacon's Mechanical History and the Deprecation of Craft Skills in Early Modern Science', *Perspectives on Science*, *25*, 521-550.