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Forthcoming in *Australasian Journal of Philosophy*

Penultimate version, August 2024

Aesthetics and Agency in Experiments

Abstract

We place agency front-and-centre in the aesthetics of science via an analysis of experimental design and performance. This first involves developing an account of scientific agency relevant to experiment. We do this via an analogy between experiments and games (as understood by Suits and Nguyen): both involve artificial practical environments designed to enable participants to exercise particular forms of agency. Second, we consider how this account of agency might underwrite an aesthetics of experiment. Experiments are well-designed not only when they generate clear, elegant results, but also when they actively confront the experimenter with experimental phenomena, afford the exercise of agency throughout experimental runs and in iterative design and tweaking, and underlie stable, intersubjective experiences across agents. We apply the account to Newton's optical work, and contrast this 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, sensibilities, and judgments in science.

Keywords: Aesthetics in Science; Agency; Experiments; Newton's Optical Experiments

Acknowledgements: We are very thankful to audiences at LMU Munich, University of Copenhagen, University of Cambridge, and University of Leeds, as well as two anonymous referees for their feedback on this paper.

1. Introduction

Aesthetics is typically grounded in experience. Yet the aesthetics of science leaves a determined distance between scientists' experience and aesthetic value. Most work focuses on theories—their elegance, simplicity, and so on—leaving scientists *qua* aesthetic agents out of the picture. Recently, some philosophers have expanded the scope of the aesthetics of science (Turner 2019; Murphy 2020, 2023; Wragge-Morley 2020; Ivanova 2021, 2022; Currie 2023; papers collected in Ivanova & Murphy 2023). 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). You can't explain science's epistemic business without understanding its aesthetic business. Still, scientific agency has as-yet found no place in these discussions.

Rectifying this, we will develop an agential notion of the aesthetics of experiments focused on how well-designed experiments position agents to experience experimental phenomena, to understand and express the agency the experiment encodes, and—across agents—enable stable, intersubjective experiences. We thus build on work in philosophy and sociology of science on agency in experiments,[1] as well as on aesthetic notions of design and function (see 4.2).

[1] For example, Pickering emphasises 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' (2012, 318). On this model, experimentation involves two forms of agency acting in turn. Scientific agents set up 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. For another important account of agency in experiments, see Barad's 'agential realism' (2007).

You might balk at the proposed link between aesthetics and agency: isn't aesthetics, you might wonder, primarily about appreciation rather than practical action (the purview of agency)? We take our approach to follow recent philosophical accounts of 'aesthetic agency'. Karen Gorodeisky, for instance, has argued that we should expand the scope of agency beyond volitional reason, to include the kinds of affective and cognitive states associated with aesthetic appreciation (see her 2022 and citations therein). We aren't committed to the precise details of Gorodeisky's account, but rather to its spirit: if we narrowly proscribe the domain of aesthetics, or of agency, then the two will indeed fail to overlap. However, our philosophical conceptions will then miss how profoundly aesthetic experience shapes and intertwines with our rational, agential and (especially in this context) epistemic lives.

Our account of the aesthetics of experiment draws on another recent work bringing aesthetics and agency together: C. Thi Nguyen's account of "Suitsian games" (2020). For Nguyen, game designers work in the "medium of agency", they shape participants' experiences of agency—approximately, the decisions and actions taken within a practical environment. We don't claim experiments are games, but argue that experiments, like games, are artificial, practical environments that encode agency. We'll argue that this underwrites not only the experiment's aesthetic value but also its epistemic power. Overall, a sufficient account of the aesthetics of science should say something about the experiences of scientists and how they exercise their agency within scientific structures, practices and institutions. Through focusing on experimental procedures as well as their outcomes, this paper represents, we hope, several steps towards such an account.

"Agency" is a well-worn and heavily debated concept across various philosophical subdisciplines. We hope that our account is sufficiently minimal in its conception of agency that it can happily fit with more specific conceptions. The main commitment required of our account (and, we suspect, Nguyen's), is the idea that at least some practical actions require an environment within which to occur. To be those actions, various conceptual and material scaffolds need to be in place. This might not hold for practical action in general, but it clearly does for both games and experiments. For the act of *folding* in poker to be that act, we need the rules of poker, cards, a game to be in play, and so forth. For the act of measuring light's 'refrangibility' (see below) to be that act, we need the relevant concept, apparatus, and experimental setup. As such, some exercises of agency require particular environments. Any account of agency which allows this, we think, should be able to accommodate our discussion.

Our argument follows three broad steps. First, we develop an account of experimental agency based on the analogy with games, developed in section 2. Second, via a discussion of Newton's optical experiments, we develop a set of agential, aesthetic properties which well-designed experiments afford through sections 3 and 4. Finally, in section 5 we introduce the notion of "experimental distance" which is crucial for understanding the kinds of agency and aesthetic experience an experimental procedure affords.

2. Experiments & Games

We'll argue that experiments generate agency in much the same way as games: namely, by setting up an artificial circumstance that affords focused practical action. In this section we'll concentrate squarely on agency, turning to the aesthetic elements downstream.

In *Games: Agency as Art*, Nguyen argues that games are a distinctive art form. Just as, say, painters use visual media, game designers 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).

Nguyen's account picks out a particular kind of game, labelled "Suitsian games", after Bernard Suit's (1978) analysis. These games involve practical struggle. One of Nguyen's examples is the role-playing game *Sign*, designed by Kathryn Hymes and Hakan Seyalioglu. Each player receives an inner truth, known only to themselves. The game's goal is to communicate this truth to the other players. Crucially, the rules of the game dictate that 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 the players of *Sign* '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). Thus, for our and Nguyen's purposes games involve setting up a set of rules and sometimes material props that enable players to temporarily take on a set of constrained goals, thus a particular kind of agency.

The *artificiality* of games is crucial for our comparison with experiments. Games are constructed to shape player experience. This artificiality allows the game designer to zero-in on the specific practical agency that they hope players will explore. 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 a recipe for crystalising that agency. Similarly, experiments are artificial setups with goals, aims and constraints to which the scientists running them strive to abide.

The core connection between experiments and games concerns what Nguyen calls "constitutive constraints": the game's specific design parameters. For 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. Paradigm experiments also involve constitutive constraints: there are a set of rules that dictate how the apparatus should be set up. 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 to experience certain forms of agency, so too does experimental design facilitate forms of agency in scientists. In running the experiment, the scientist takes on and explores the temporary agency encoded in experimental design.

Like artworks, games have a "prescriptive frame"—a set of social norms facilitating how the work should be experienced (Nguyen 2020, 121). When viewing a painting, we focus on the front of the canvas, for example, rather than the back or the blank space around it. Art galleries encourage certain prescriptive frames—encouraging us to observe the art from particular angles and distances—to highlight relevant parts of the work. To experience a game, we must follow the rules and aim for the goals that are part of the game's design; these isolate and focus our attention on particular features. *Sign* is 'a framed experience of inventing the means of communication' (ibid., 130). If I state my inner truth out loud, then I won't be experiencing the game. We'll see similar prescriptive frames when we turn to Newton's experiments.

In section 4, we will return to Nguyen's analysis and examine how aesthetics intersects with agency. For now, let's take our discussion of agency and consider experiments, highlighting three key aspects of experimental agency which have analogues in Nguyen's account of games: the prescriptive frame, the distinction between designing and conducting an experiment, and the role of the designer.

Firstly, a feature of both Nguyen's account and ours is the role of the prescriptive frame in guiding experience. Experimental procedures require particular behaviour from scientists: observing, measuring, pouring, stirring, twisting dials, positioning, watering, incising, collating, cleaning, and so on. However, in experimental design, scientists do not simply stipulate a set of apparatus and operations, but a prescriptive frame, specified by a combination of goals, rules, background assumptions, etc. In the double-slit experiment, for example, the relationship between the expected and the actual array of electrons is crucial.[2] When checking the experiment's setup, one might concern themself with the exact positions of the slits and the photon detectors, the quality and position of the laser beam, and so on. But in performing and experiencing the experiment, the crucial expectation-versus-outcome relationship takes centre stage—a key aspect of the prescriptive frame.

Secondly, a distinction central to Nguyen's analysis and ours is between the designer and the participant. While the designer of a game can also participate in play, we can draw apart the experiences of a player from the properties of game design, which are geared towards generating those experiences. Similarly, in experiments, we can distinguish between those who design experiments and those who run them, i.e., cases where someone designs an experiment, and refines it, and then passes the design on for others to conduct the experiment. This includes cases where lab technicians run an already-designed experiment, in pedagogy where students perform an experiment to experience well-known experimental phenomena, or (perhaps more controversially[3]) when different labs attempt to replicate results. This distinction is messy in

[2] The double-slit experiment demonstrates that light and matter can satisfy the apparently incompatible classical definitions for both waves and particles. As the name suggests, the experiment involves sending a stream of photons (or electrons or neutrons) through two parallel slits, projecting them onto a screen. (For a brief discussion of this experiment and its history, see Rodgers 2003.)

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

practice: the design of novel experiments or novel experimental applications typically involves runs of the experiment to establish validity, perhaps analogous to 'play-testing' games. Nevertheless, we find it helpful to disambiguate designing from conducting an experiment.

Which brings us, thirdly, to the role of the designer. 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 in terms of their outcomes (both by philosophers of science, and in scientific papers themselves). This results in the agency of experimenters being left out of the narrative. By making agency our focus, we can think about an aesthetics of experiments that goes beyond the product of experimental design to incorporate processes—both in experimental design and experimental runs—as well. The analogy between game-design and experimental design (and 'play-testing') facilitates our focus on agency by highlighting the design process as an important aspect of experimental practice.

Before continuing, let us highlight some important differences between experiments and games: we're in the business of drawing analogies, not claiming that experiments are games. The first difference concerns function. For games, this is (often) enjoyment. By contrast, experiments (often) have epistemic goals: scientists conduct experiments to learn something about the world. No doubt there are many counterexamples to this claim: many games have pedagogy or various forms of exploration in mind; some experiments are also primarily pedagogical, and, while some games are experimental, some experiments take the forms of games. Indeed, experiments in developmental psychology often literally involve a child playing a game. Regardless, *paradigmatically* the point of taking on the temporary agency of Suitsian 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.[4]

A second difference concerns how practical environments are constrained. 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).[5] The core focus of Nguyen's account is the setting of rules by the designer. Similarly, in an experiment, there are constraints from experimental design. However, there are also constraints 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 instance, comprises the scientific agent and their experimental apparatus (the "slits", for example), but also the particles themselves. We can therefore see a further difference between *paradigmatic* games and experiments: in games there are players and constraints; in experiments there are the scientists, the experimental constraints, and the experimental specimens, or (if you want) 'the world'[6].

The role of the world is important because the epistemic power of an experiment partly turns on its results being not wholly controlled by the experimenter: if one is to test a hypothesis and potentially generate surprising results, your experimental target must have a range of possible responses to the experimental intervention. As Mary Morgan put it in the context of experiments

[4] Nguyen connects games to artworks more generally as being designed for the purpose of generating aesthetic experiences, in this instance, experiences of agency, as we will see below. If we are right, then it may be that many scientific objects and practices are also geared towards generating aesthetic experiences. Perhaps experiments are artworks, or perhaps so much the worse for that account of what an artwork is.

[5] 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.

[6] This point applies only paradigmatically: 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. Further, there might be scientific 'experiments' where the world plays little role if, for instance, we insist that abstract scientific models count as 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).

We thus 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 set of constraints beyond the scientific agent's and the experiment's: those of the specimens themselves.

Caveats regarding aim and constraints aside, the analogy between games and experiments that we have drawn allows us not only to consider the final product of an experiment, i.e. the results (measurements, data, etc.), but also to explore the way that their constitutive constraints shape agency in the scientists running the experiments. But what kind of agency and to what purpose? To develop our answer, we'll now turn to a more concrete case: Newton's optical experiments.

3. Agency in 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 taken together are supposed to constitute a single proof for the proposition. Each experiment reveals some property of light. 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,[7] 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.

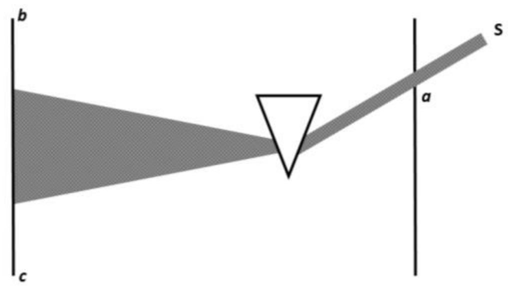

Figure 1: Experiment 3

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

In experiment 3, Newton describes the experiment represented in figure 1, involving a hole in a window shutter (*a*), through which a narrow beam of sunlight (*S*) enters the room, to be subsequently 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:

[7] For a recent account of the probative force of Newton's proof by experiments, see Walsh (forthcoming).

> 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 refracted more than other rays, causing them to land higher on the screen than rays that are less refracted. And so, refrangibility 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, and hopefully most obviously, Newton's descriptions of his experiments are descriptions of a set of apparatus and constitutive constraints that together generate experimental goals. Embedded in a particular conceptual environment (concepts such as 'ray' and 'refrangibility' are articulated by a set of definitions and axioms[8]), scientists use apparatus (apertures, prisms, etc…), as well as a set of rules—where to place the prisms and apertures, for instance—to conduct the series of experiments. In so doing, they take up a form of agency towards, say, detecting the heterogeneous refrangibility (or otherwise!) of light. By analogy with games, those performing the experiment are players taking up the temporary goal of understanding the refrangibility of light.

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[8] The definitions and axioms are listed at the start of Book 1. For an account of their role as part of the prescriptive framework of Newton's *Opticks*, see Walsh (forthcoming).

Second, 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 mention colour. Instead, he bids us to focus 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.[9] This is significant because, by limiting the description to certain features, Newton is controlling the prescriptive frame, that is, 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 the experimental agent needs to engage with these experiments in a certain way if they are 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.

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

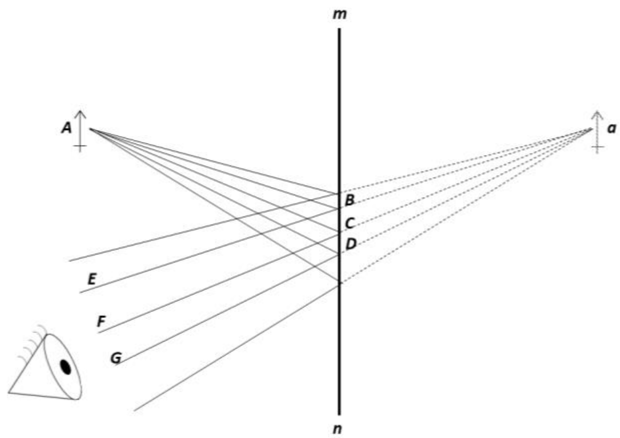

Figure 3: Axiom 8 demonstrated for reflection

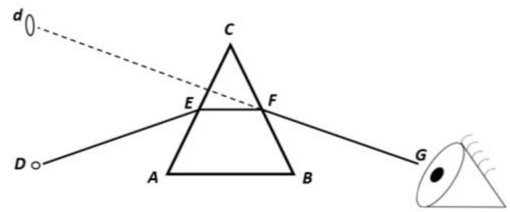

Figure 4: Axiom 8 demonstrated for refraction

A third thing to notice is that Newton *qua* experimenter is part of the experimental setup: he is playing the game, as it were. Most obviously, this is demonstrated by the fact that he must position himself differently in each experiment 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.

This is no accident: the relevance of the observer's perspective is encoded in the axiomatic framework of the inquiry. 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 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*. Thus, Axiom 8 both provides information about how the experimenter should be positioned, and uses that positioning to make sense of the observed phenomenon.

Further, in Newton's experiments, the experimenter might be considered part of the experiment in perhaps more mundane ways. For example, they 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, they interact with the light, albeit indirectly, via the experimental apparatus. Experiments 3 and 4 are 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 more dynamic: the experimenter rotates a prism, or manipulates 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 fourth thing to notice about Newton's experiments is that experiment 3 is plausibly considered a "core experiment".[10] Newton describes a single experiment, the parameters of which are adjusted over the series of eight experiments (including experiment 4, as we have seen). 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.[11]

[10] 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.

[11] 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.

Moreover, the way Newton describes these experiments gives his readers enough information to replicate the experimental sequence, beginning with experiment 3, and then to generate even more new experiments of their own.[12] In other words, it is plausible that Newton intends that these experiments will be enacted,[13] rather than merely read or "virtually witnessed".[14] Through performing the experiments, experimenters explore the capacities of light (and of themselves as interactors with light) across a variety of slightly differing constitutive constraints. (That some experiments are 'core', designed specifically to be explored and altered, will be crucial when we turn to aesthetics downstream.)

And so, to begin to answer the question we raised at the end of the previous section ('But what kind of agency and to what purpose?'), Newton's optical experiments facilitate agency, not just by giving the experimenter control over the initial experimental setup, but also by making them part of the complex epistemological and material system that constitutes the experimental process. As part of the system, the experimenter asserts a kind of collaborative agency wherein the three-way interaction between experimenter, apparatus and specimen, guided by the prescriptive frame, enables the experimenter to tweak, alter, adjust and add parameters. And so, the agency bestowed by the experimental design facilitates ongoing practical action for the experimenter.

[12] 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).

[13] We may never know for certain exactly how Newton intended for his readers to interact with his work. The texts themselves, however, offer some insight regarding his authorial intentions. The features we have highlighted, for example, the core experiment, the sequence of variations, and the level of description, especially when interpreted within the Baconian experimental tradition, support the idea that that Newton presented his proof by experiments with this sort of enactment in mind. (See [redacted] for a fuller defence of this position.)

[14] "Virtual witnessing" is understood as using language to convey an experiment in such a way that the reader feels as though they have experienced it—this vicarious experience enables the reader to confer agreement (see Shapin 2011, 60-65).

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 now argue, there are crucial aesthetic components to such agency.

4. An Aesthetics of Experimental Agency

In demonstrating a connection between scientific agency and aesthetics we won't commit ourselves to any act of scientific agency having an aesthetic dimension, or to there being some kind of necessary connection between agency and aesthetic sensibilities or judgements. Rather, it is sufficient for our account to show how paradigmatically scientific acts of agency, such as running and designing experiments, often involve aesthetic properties and are geared towards generating and making use of such properties.

You might wonder what, if anything, is distinctively *aesthetic* in our account of scientific agency. Indeed, both Newton's optical work and the double-slit experiment are—as with science generally—highly *epistemic* pursuits. As such, accounts of aesthetic sensibilities and judgements which demand they be decoupled from epistemic sensibilities and judgements might be non-starters for our project. Note that Nguyen's project faces a similar objection: if aesthetic judgement is about sensibility and judgement, how could it concern *practical action*? Nguyen's response is to appeal to a Deweyan notion of art: approximately, art 'crystalises' the aesthetic features of everyday experience. Music, for instance, captures some of the aesthetic qualities of our everyday auditory experience. As music is to sound so games are to agency and, we think, so experiments are to *epistemic agency*. We don't think that agency being epistemic precludes it from also being aesthetic, indeed, we think the analysis provided here provides good reason to think that the two are at the very least intertwined (see Turner 2019, 5, for discussion of possible relationships between aesthetic and epistemic sensibilities). We do not attempt, here, to take a stance on the exact relationship between the epistemic and the aesthetic. But we think that so long as one doesn't take them to be mutually exclusive,[15] the aesthetic-epistemic properties we'll now bring out constitute a rich starting point to consider an aesthetics of scientific agency. In section 4.1, we'll develop five features of experimentation which we think are rightly considered aesthetic, and in section 4.2, we'll turn to design.

4.1. *Aesthetic Agency in Newton's Optical Experiments*

There are multiple ways in which Newton's optical experiments can be said to have aesthetic value. Perhaps most shallowly, there is aesthetic pleasure arising from the perceptual properties of experimental phenomena: in earlier work, he described optical experiments as 'a very pleasing divertisement, to view the vivid and intense colours produced thereby' (Newton, 1959-1977: Vol. 1, 92). We might also take them to have aesthetic value in Ivanova's sense of good design (see below): they efficiently and effectively display optical phenomena in a manner which compels experimenters to assent to Newton's theoretical propositions. However, we also think Newton's experiments offer insight into the relationship between aesthetics and agency in scientific experiments.

First, 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 prescriptive frames is a feature Newton's

[15] For instance, a view such as Todd's (2008), which claims that apparently aesthetic judgements and claims in science are in fact masked epistemic claims, seems to us to be perfectly consistent with our account here.

experiments share with games and other artworks. In short, both experiments and art must 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.

Prescriptive frames bring the aesthetic and epistemic together by enabling *experiential intersubjectivity*: insofar as different individual scientists take up the same constraints and activities, there is a continuity across them regarding the agency they exhibit and the experiences they have. 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. Continuity of aesthetic experience here underwrites continuity of both aesthetic and epistemic intersubjectivity.

Second, well-designed experiments facilitate experimenters' developing and enacting 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. 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.[16] 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.[17] Recall that Newton's third experiment is best understood as a core experiment: it encodes a kind of agency, exploring the properties of light through use of apertures and prisms, that is intended to be, as it were, "played around with". It isn't then that skills with this mode of agency matter simply for understanding the experimental phenomena, but also for developing novel applications and exploration.

The relationship between embodiment, skill and aesthetic sensibilities is a complex one that we've neither the philosophical nor empirical space to unpick here. Regardless, at least some scientific work heavily highlights the interaction between aesthetic sensibility and embodied skill.[18] Moreover, the close ties between embodiment and experience, and between aesthetics and experience, makes them natural bedfellows. Our discussion of "practical harmony" below may make this idea more palatable as well.

This brings us to a third insight: well-designed experiments afford opportunities for aesthetic experience of agency. 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—we'll refer to this below as "deep play"—with apertures, prisms, and such like.[19] In so-doing, working within

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[16] 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)

[17] 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).

[18] See, e.g. Kirsch et. al. (2016) and Ticini et. al. (2015).

[19] Similarly, incredibly advanced technology and skill are 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

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. We don't take ourselves to here be committed to every act of agency having an aesthetic dimension, or that every engagement with experimental agency involves aesthetics, but simply that in many cases they do.

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)[20] 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, and the connection between practical agency and aesthetic sensibility.

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":

> 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)

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affects the aesthetic experience of one's agency is fleshed out below in terms of Nguyen's notion of "practical harmony".

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

While the harmony of solution is something that both a spectator of a game and the player themself can access, 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 analyse 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.). Moreover, where things go *wrong*, these disharmonies, are experiences which are crucial for seeing how the design needs tweaking (the same might be said, *mutatis mutandis*, for experiences with core experiments).

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 plausibly yields epistemic as well as aesthetic dividends. 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, as with core experiments.

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 inspires 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.

We suspect harmony of action and capacity act as common aesthetic goals in experimental runs. Where harmony of action and, rarer but we think still crucial, capacity, misfire or fail to emerge through the scientist's actions, they will guide further tweaks, re-runs, and variations in the various features constitutive of the experiment. This is an aspect of the skilled behaviour required of experimenters that goes beyond whether the right result was obtained.

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 forms of epistemic and practical 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, but in how that design generates forms of agency. Drawing from the above, here is an initial list of how an experiment may generate agential aesthetic goods:

(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. All of these features draw aesthetics and epistemic sensibility and judgment together in a way which we think accords with many views on the relationship between these, so long as they do not treat them as mutually exclusive. We'll close with a more critical discussion which focuses on the first feature in our list: directness. But before that, we'll briefly address how our view squares with existing work on the aesthetics of experimental design.

4.2 *Aesthetics and Design*

The match between an object's properties and its function is a source of aesthetic value (Parsons & Rueger 2000, Turner 2019, Ivanova 2021, Murphy 2023), and this underwrites an aesthetics of design. An aesthetics of design focuses on the beauty of a connection between an intended goal and how the designed object goes about achieving that goal. In this vein, Milena Ivanova (2022) points to the connection between design and experimental output. One aspect of the beauty of, say, the double-slit experiment, is that its results are (in some sense) crystal-clear. The experimental phenomena—the patterns the photons leave after shooting through the slits—is distinctly captured by the experimental setup. While experiments can be appreciated in this way, we hope to have shown that there is more to say about the aesthetics of experimental design. Good design in experiments can also be understood in terms of how it generates aesthetically (and epistemically!) rewarding agency in scientists performing the experiment.

Consider the double-slit experiment again, once voted by readers of *Physics World* the "most beautiful experiment in physics". One way in which respondents evaluated the experiment aesthetically was in terms akin to 'deep play': part of the beauty of the double-slit experiment lies in 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' (Crease 2002, 20). Crease considers this 'deep play', because it involves 'being actively engaged with something outside ourselves that is responding to us' (ibid., 19). Thus, in deep play, the scientist themself engages with, and observes the results of, experimental manipulation. 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. This is also reflected in a recent qualitative study which found that one dimension of the aesthetic value of experiments comes from the performance of an experiment, especially when it requires the exercise of creativity and challenges experimenters' capacities (Ivanova et. al 2024, 10).

How do aesthetic qualities play into experimental agency in design? The quick answer is to follow Nguyen. Just as well-designed games afford player's aesthetic experience of their agency as well as the capacity to understand and develop that agency, so too do well-designed experiments enable scientists' aesthetic experiences and agential expertise to be acted out and developed.

Nguyen starts from discussion of the aesthetic experience of playing games and, from this, analyses what makes for good game design, that is, affording aesthetically rewarding—striving—game play. Similarly, through design properties and the prescriptive frame, we see a form of agency emerging in experiments. Thus, when we say we understand experimental design *in terms of* scientific agency, we mean both that scientists having certain kinds of agential capacities is necessary for understanding experimental design, and that specific forms of agency arise in the performance of an experiment. Indeed, facilitating agency is, in part, what experiments are for.

What would make for *good* experimental design in this context? Ivanova has highlighted the relationship between experimental design and the experiment's results: to continue with our example, the double slit experiment provides a precise demonstration of a crucial phenomenon underwriting quantum mechanics. And for Newton, a well-designed experiment offers an especially illuminating experience of the phenomenon and affords "compelled assent".[21] But we have provided a more diverse set of aesthetic goods that experiments afford: directness, stability/shareability, embodiment, deep-play, and various forms of harmony. Well-designed experiments accommodate these as well.

This account of the aesthetics of design also provides some hints as to some ways in which experimental design and performance might go awry. For instance, there could be a mismatch between the intended agential properties and the affordances provisioned by the constitutive constraints and prescriptive frame. Say, the experimental apparatus might be too unwieldy or time-

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[21] See, e.g. (Walsh 2017b, 876-877).

consuming for effective deep play. There could also be cases of what Currie (2021) has called 'misalignment', where the stakes of success undermine the absorption required for some aesthetic value.

There is no doubt a lot more to be said regarding these agential aesthetic goods. We might ask whether they trade-off against one another, what design principles might work towards them, and be concerned about their overall relationship with the epistemology of experiments. Regardless, we take our analysis of the agency of experiments to open up space to consider not only the aesthetics of experimental runs but also experimental design.

5. Experimental Distance

We have thus far argued that a crucial source for aesthetic and epistemic value in science is 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 pre-empt 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: their agency is in some substantive sense indirect. 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.

Newton's optical experiments and how they are presented harkens to an often-false perception of scientific work: a lone scientist manipulating a relatively simple apparatus to generate a clear result. Here, there is a direct engagement between scientist and experimental phenomenon, and our discussion of agency seems to apply quite straightforwardly.

But most experiments are not like this. Consider a simplified 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 for the experimental phenomena: 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 distance. 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 accommodate such cases, a view like ours which emphasizes agency might have more trouble. 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, in which human agency is removed from many or all aspects of the conduct of an experiment beyond their design (Holland & Davies 2020).

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 have a reduced 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, and we think these responses open a range of new questions in the aesthetics of science, so as opposed to cheering in support of one, we'll instead provide a speculative discussion of each.

First, perhaps distance reveals something which is lost when science "goes big", i.e., when there is great distance between the experimenter and the experimental phenomenon. While 'large' experiments have much to offer, perhaps they lose something important: the embodied aesthetic agency of the scientist. In the spirit of Ian James Kidd's discussion of Marx and scientific creativity (2021), we could say that in restricting scientist's opportunity for aesthetic experiences of their own agency, big science alienates scientists from their creative products. Further, this might reduce feelings of satisfaction and sense of well-being of scientists within their work, given the apparent associations between aesthetic experience on the one hand, and sense of purpose and flourishing within scientific research on the other (Jacobi et al 2022). Another possible implication of our analysis is that opportunities for aesthetic experiences of agency fluctuate throughout an individual scientist's career; as scientists advance and become leaders of projects, their time is spent dedicated to grant capture and management, reducing their direct involvement in experimental work.[22]

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. Most obviously, although agency might not lead to an experience of the phenomenon itself, it is nonetheless likely crucial for the various tweaks, subtle interventions and so on required even in the most 'automated' of experiments. That is, distance concerns the experimental phenomena, and our account of aesthetic agency concerns features beyond the phenomena: the scientists' experience of harmony, for instance. Further, understanding how distance is mitigated—how the results of 'big' experiments are presented to scientists themselves—itself is a feature of scientific agency and the aesthetics of experimental design that deserves attention. Just as 'paper technologies' in the seventeenth century (i.e. the widespread use of note-taking, record-keeping and letter-writing) generated new affordances for natural philosophers,[23] 'digital technologies' can be understood in part as scaffolds for novel scientific agency which in part act to mitigate the challenge of agential distance (see Kassell 2016 for historical discussion).

Second, notice that Nguyen's analysis of games applies fairly straightforwardly to instances—particularly pedagogical ones—in which an experiment has already been designed and is "fixed" in some sense, and 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

[22] We thank an anonymous reviewer for highlighting this. If true, this would offer an interesting contrast with a qualitative study on uses of imagination in science, wherein junior scientists felt less able to use their imagination in their work, and were more sceptical of its value, compared with more senior scientists (Stuart 2019).
[23] Pieter Best (nee Present) analyses such affordances in terms of contemporary notions of extended and distributed cognition (Present 2019).

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. Insofar as performing such experiments play a crucial role in scientists developing their aesthetic and epistemic sensibilities and judgments (Currie 2022), their directness is important for understanding the nature of scientific knowledge.

A third 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.

For one example, we have emphasized the proceduralism of experiments: experiments should not be thought of only in terms of results, but as dynamic processes. 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, often involving 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 (Leonelli 2016). 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 (2012)) "the world's", perhaps understanding the analysis of experimental results in terms of agency is also called for.

Finally, a fourth response: perhaps we should make space for considering "distributed agency" or "distributed aesthetics" in 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 diffusible. Science does its social-epistemic work not simply in how scientific communities marshal collective epistemic activities, but in how they situate the agency of various actors. In Nguyen's analysis, he highlights how the harmony of action is not limited to players as individuals. Rather, group sports and similar activities can provide '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 one aspect of our account (that appealing to experiencing the experimental phenomena itself), 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.

Our view, in combining highly agential notions of aesthetics with the epistemic business of experimentation, provides a very human conception of science: which is to say, humans are both epistemic and aesthetic beings, and successful science depends on the integration of these aspects of ourselves. Recently Michael T. Stuart has argued that a distinct advantage of artificial intelligence in scientific contexts is the capacity to find "ugly" solutions outside of spaces where aesthetic agents like ourselves would consider (2023). Understanding the role of aesthetic agency in scientific practice is both necessary for grasping current science, but also how science might be in the future.

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