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ARTICLE

Form and Content: A Defense of Aesthetic Value in Science

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Abstract

Those who wish to defend the role of aesthetic values in science face a dilemma: aesthetic language is either used metaphorically for what are ultimately epistemic features, or it is used literally, but the importance of such values for science is unclear. This article introduces a new account that gets around this problem by considering an overlooked source of aesthetic value in science: the relation between form and content. A fit between the content of a thought experiment and the way in which that content is formulated can have important epistemic payoffs by contributing to scientific understanding.

Introduction

The role of aesthetic value in the scientific domain is beginning to attract attention. Aesthetic value is not limited to beauty, but philosophers have taken as their starting point claims from mathematicians and scientists emphasizing the value of beauty in their domain (McAllister 1996; Breitenbach 2015; Ivanova 2017a, 2017b; Dutilh Novaes 2019). Although the discussion has focused primarily on scientific theories, there is also some work on aesthetic evaluations of experiments (Parsons and Rueger 2000; Ivanova 2021) and scientific thought experiments and their relations with artistic fictions (Elgin 2014; Murphy 2020a). My focus here is on thought experiments, but I intend for the key features of my account to extend to other areas of scientific practice, especially theoretical models.

This article, via the case of thought experiments, introduces a new account of aesthetic value in science. Section 1 discusses why thought experiments ought to be included in the aesthetics of science. Section 2 presents a dilemma for aesthetics-of-science projects: On the one hand, it appears that when scientists utilize aesthetic language, they use it in a merely metaphorical sense. That is, what is really being picked out is the epistemic features. On the other hand, if the language is genuinely aesthetic, then it appears difficult to defend the usefulness of aesthetic values in the scientific domain. A challenge for an aesthetics-of-science project is to show that

aesthetic language is used literally while demonstrating that such evaluations play an important role in science. In section 3, I outline a source of aesthetic value from the philosophy of art that is currently overlooked in the aesthetics-of-science literature. This is the relation between the content of an artwork and its form. In section 4, this is applied to the case of thought experiments via two examples from Darwin that are similar at the content level but differ in their formal features. I end, in section 5, by demonstrating how this offers a novel and promising way of defending the role of aesthetic features in science without reducing them to purely epistemic features. This is because a fit between form and content is a genuine source of aesthetic value that can contribute to understanding by aiding our formation of useful imaginings.

1. Thought experiments and the aesthetics of science

There are (at least) two reasons why thought experiments ought to be considered in discussions of aesthetics in science. First, thought experiments are evaluated using aesthetic language (Murphy 2020a). Take, for instance, Galileo's falling bodies. This has been described as "the most beautiful thought experiment ever devised" because it is "brilliantly original and simple as it is profound" (Brown 2004, 24). This example also came in second in a poll of the most beautiful experiments conducted by *Physics World* (Crease 2002). Brown sets out the thought experiment (alongside an image of balls being dropped from a tower) in the following way:

> Aristotle and common sense hold that a heavy body will fall faster than a light one. (We can symbolize this as $H > L$). But consider ... a heavy cannon ball is attached to a light musket ball ($H + L$). It must fall faster than the cannon ball alone ($H + L > H$). Yet the compound object must also fall slower ($H + L < H$), since the lighter part will act as a drag on the heavier part. Now we have a contradiction ($H + L > H$ & $H + L < H$). That's the end of Aristotle's theory. But we can go further. The right account of free fall is now perfectly obvious: they all move at the same speed ($H = L = H + L$). (2004, 23–24)

This is an example of a "beautiful" thought experiment in science.[1] But as we shall see, there are also negative evaluations of thought experiments that include aesthetic terminology. An example is Darwin's whale thought experiment, described by his contemporaries as "monstrous" and "gross," which I discuss in detail in section 4.[2] It goes as follows:

> In North America the black bear was seen by [the explorer] Hearne swimming for hours with widely open mouth, thus catching, like a whale, insects in the water. Even in so extreme a case as this, if the supply of insects were constant, and if better adapted competitors did not already exist in the country, I can see

[1] Additionally, in a 2012 survey conducted by edge.org that asked scientists and philosophers what their "favourite deep, elegant, or beautiful explanation is," around 1/6 of answers were either clear examples of thought experiments, or they were imagined scenarios that we might include under a broader category of thought experiments (Stuart 2018, 530).

[2] Agassiz described the thought experiment as "truly monstrous" (Stuart 2016b, 31), and Owen (1860) referred to it as "gross."

> no difficulty in a race of bears being rendered, by natural selection, more and more aquatic in their structure and habits, with larger and larger mouths, till a creature was produced as monstrous as a whale. (Darwin 1859b, 184)

The second reason why thought experiments ought to be considered in the aesthetics of science is that they are often compared with works of literary fiction, which are, of course, evaluated aesthetically. Like works of literature, thought experiments are designed to engage the imagination by inviting us to consider a fictional scenario, and they often take a narrative form. Given these similarities, there have been attempts to defend the cognitive value of literature via philosophical and scientific thought experiments. In such views, literary fictions can teach us something about the world or ourselves because they function like a thought experiment (John 1998; Carroll 2002; Davies 2007; Elgin 2014; Bornmüller et al. 2019). Additionally, Godfrey-Smith (2006) claims that scientists often talk about idealized and simplified models as if they were real, "concrete" systems. This has led to a set of views stating that modeling involves interacting with fictions in a way that is analogous to our engagement with fictions in art. Many have drawn on Walton's theory of make-believe to develop their account (Frigg 2010; Toon 2012; Salis and Frigg 2020).[3]

The rise of the fiction view of models has prompted discussions of the role of the imagination in science, and a volume dedicated to the topic has now emerged (Levy and Godfrey-Smith 2020). Others who do not subscribe to the fiction view have maintained that there is an important place for visual, mental images—and the imagination more generally—in thought experiments, modeling, and theorizing (Weisberg 2013; French 2020a, 2020b). This interest in the commonalities between scientific models and thought experiments and artistic fictions, as well as the nature and role of imagination in each, opens the way for an aesthetics of models and thought experiments.

However, I'll now outline a set of worries for any aesthetics-of-science project that threatens the idea that there are genuine aesthetic evaluations in science that also have an important epistemic function.

2. The aesthetics of science: a dilemma

It could be argued that when scientists or philosophers of science describe some aspect of science aesthetically, what is really being said is that it is successful or unsuccessful. For example, when Galileo's thought experiment is described as "beautiful," *beautiful* is meant in a metaphorical sense. That is, it is being used to comment on how the thought experiment successfully undermines Aristotle's theory. Similarly, when Darwin's whale thought experiment is described as ugly, "monstrous", or "gross", these seemingly aesthetic terms are merely used to communicate how the thought experiment drastically failed. The idea is that aesthetic language can be used in a loose way, so the application of aesthetic vocabulary alone does not indicate that there is something genuinely aesthetic about these evaluations. This issue has been raised by Todd, who asks whether

[3] Salis and Frigg apply their view to models and thought experiments. See also Meynell (2014) for a Waltonian view of scientific thought experiments.

"the apparent aesthetic judgements of proofs and theories made by practitioners in science and mathematics should be taken at face value, or whether there are good reasons to doubt that their appraisals—and, hence, the nature of their appreciation—are really aesthetic at all" (2008, 62).

Todd discusses a number of views claiming that the beauty of a theory can be an indicator of the truth of a theory. We can focus on his discussion of the work of McAllister (1996), which he takes to be one of the most developed accounts of the legitimate role of aesthetics in the assessment of theories. McAllister argues that the aesthetic plays a role in science, but this does not threaten a rationalist image of science, that is, one in which preference for scientific theories is dictated by their logical consistency and empirical adequacy. McAllister explains the connection between the beauty of a theory and its truth or empirical success, with reference to the aesthetic canon. In this view, scientists' aesthetic preferences have been shaped over time to match the features of successful theories. The connection is based on aesthetic induction; when a theory is regarded as beautiful, this is because it is similar to existing, successful theories (i.e., it accords with the aesthetic canon). Therefore, it is more likely to be true or empirically successful (McAllister 1996, 33–34).[4]

McAllister reduces beauty to features such as simplicity, symmetry, elegance, harmony, and visualizable structures. Because of this reductionist approach, Todd is skeptical that the term *beauty* is really being used in an aesthetic sense when applied to scientific theories. He motivates this by highlighting how some of these terms are used in theory assessment without making a link to beauty or aesthetic value more broadly. Therefore, Todd argues, we should understand such terms as being used in a way that actually tracks epistemic features: "there are strong grounds for suspecting that what appears to be aesthetic claims may often be, if perhaps not always are, really masked 'epistemic' functional ones" (2008, 72).

Todd does not give up on theories of aesthetics in science, and he accepts that the relationship between the aesthetic and the epistemic is not a straightforward one.[5] He does, however, state that there is a challenge for those who want to defend the genuine aesthetic nature of judgments of beauty and so on in science. The challenge is to provide a theory of "aesthetic value, appreciation, or properties" that will demonstrate "how theories and proofs might fit the general contours of more paradigmatic examples of objects of aesthetic appreciation, such as artworks and natural objects" (Todd 2008, 63). For instance, Todd argues that the use of the term *simplicity* in the case of describing a theory or an idea is different than when describing a Mondrian painting; thus, "it is the context of use that determines whether they [terms] are being used to signify aesthetic interest or value, or not, and this McAllister and others generally fail to notice" (2008, 70).

[4] Ivanova (2017a) connects McAllister's work to the "mere exposure effect," in which people develop a preference or a liking for something based on their increasing familiarity with it. For example, a psychology study by Cutting (2003) demonstrated that the mere exposure to certain impressionist paintings led to an increase in the participants' positive response to the paintings. The limits of Cutting's research have been discussed by Meskin et al. (2013), who carried out an alternative study demonstrating that exposure to what is taken to be bad visual art, Kinkade's paintings, did not lead to an increase in the participants' liking of the works. Rather, exposure decreased liking.

[5] In the philosophy of art, there is great debate surrounding whether the cognitive value of an artwork counts toward its aesthetic value.

On the other hand, it can be emphasized that if aesthetic judgments of "beauty," "elegance," and so on are genuinely aesthetic and cannot be reduced to epistemic features or do not have any kind of epistemic role, then we are left with a need to explain why such values are significant in science and, consequently, why they should be of any interest to philosophers of science. That is, the use of aesthetic terms is perhaps *merely* aesthetic. Although Todd focuses his article on the former claim—that is, that such judgments are not genuinely aesthetic—he also outlines another line of skepticism. In the "rational model" of science, "appeals to aesthetic factors in theory assessment look to be entirely out of place" (Todd 2008, 62; see also McAllister 1996). In the context of thought experiments, we could see how a similar position could be taken. Consider John Norton's view that thought experiments are just arguments and that their epistemic value can be reduced to their value in making an argument (1991, 2004). Norton may accept that, say, Galileo's thought experiment is beautiful and that scientists and philosophers take it to be so. And he may further agree that this is a genuine aesthetic response. However, in Norton's account, whether or not the thought experiment has aesthetic value is insignificant when it comes to determining its epistemic value. Norton dismisses the "picturesque" qualities of thought experiments, such as their narrative form, the particular objects that are described, and their use of mental imagery. It is therefore plausible that he would also include properties like beauty or ugliness on this list. For Norton, these features do not contribute to the strength of a thought experiment as an argument and hence carry no epistemic weight.[6]

To clarify, the dilemma for proponents of the value of aesthetics in science is as follows:

a. The application of aesthetic terms to science (e.g., to theories, experiments, and thought experiments) is merely metaphorical and should ultimately be regarded as describing epistemic features, *or*
b. The application of aesthetic terms to science (e.g., to theories, experiments, and thought experiments) is literal, but these aesthetic features are scientifically irrelevant.

In what follows, I offer a way to solve this dilemma by demonstrating how genuine aesthetic values can play an important role in science. In doing so, I take on the challenge of showing how aesthetic evaluations in science can be aligned with evaluations of less contentious examples of objects of aesthetic appreciation, namely, works of art.[7] I do this by moving away from a focus on the use of (apparent) aesthetic terminology, such as *simplicity*, *elegance*, or *beauty*, by scientists, philosophers, or mathematicians, which is the way that analyses of aesthetic value in science usually proceed. Instead, I turn to the philosophy of art to consider a particular theory of

[6] Here, I am taking Norton's view as an example of an account that may dismiss the aesthetic value of thought experiments as irrelevant to their value in science, but I do not discuss his view further. See Stuart (2016a) and Brendel (2018) for detailed discussions of Norton's position.

[7] For alternative responses to Todd's claims, see Dutilh Novaes (2019) and O'Loughlin and McCallum (2019). Currie (forthcoming) and Turner (2019) discuss the connection between aesthetics and the epistemic aims of science, also departing from Todd's position.

aesthetic value that is currently overlooked in the philosophy of science that focuses on the relation between form and content in artworks. This will provide a more robust argument for the significance of aesthetic value in science because my alternative is grounded in theories of such value rather than being reliant on the mere use of aesthetic terminology.

3. Form and content in aesthetics

A focus on the relation between form and content is common in accounts of the aesthetic appreciation of artworks.[8] For example, Levinson (1996) states that when we attend to an artwork (or an aspect of an artwork), the pleasure we derive from it is aesthetic when "regardless of which aspects of it are attended to, be they psychological or political or polemical, there is also attention to the *relation* between content and form—between what a work represents or expresses or suggests, and the means it uses to do so" (1996, 10).[9]

Consider, for example, Picasso's *Guernica*, created in 1937 in response to the bombing of Guernica during the Spanish civil war. The painting explores the horror of war, and it expresses this in a distinctive way—the composition of injured children, women, and animals; the use of distorted lines and fragmentation; the way in which the animals and humans are positioned as jumbled together; and the colors of the work being restricted to black, white, and gray, which adds to the starkness of the painting, allowing us to focus on the structure of what is depicted. Similarly, Toni Morrison's (1988) novel *Beloved* is set in the aftermath of the American Civil War and tells the story of Sethe, a formally enslaved woman, and her family. The novel pieces together Sethe's story and her escape from slavery and the tragedies that occurred along the way. When we consider what the work conveys and its cognitive and political import, we can think about how that content is bound up with how it is expressed—the particular events described regarding the lives of Sethe and her family; the use of rich imagery; the style of Morrison's writing, which incorporates elements of African American folklore—and in the structure of the work, such as the presentation of both the past and present, which conveys how the two are intertwined in the characters' inner lives. Focusing on literature, Levinson explains that aesthetic satisfaction in artworks is "precisely when such symbolic or moral content is apprehended in and through the body of the literary work itself—its sentences, paragraphs and fictive events—and not as something abstractable from them . . . . Aesthetic appreciation of art thus always acknowledges the vehicle of the work as essential, never focusing only on detachable meanings or effects" (Levinson 1996, 7).

Levinson includes a literary work's "sentences, paragraphs and fictive events" (Levinson 1996, 7) as part of its form. But it is worth noting that views regarding the

[8] In the conclusion of his article, Todd (2008) briefly suggests (but does not flesh out) a view that focuses on the relation between form and content as a possible direction for an aesthetics of science.

[9] Levinson grants that we could take pleasure in the formal features of a work (e.g., the particular arrangement of lines, brushwork, color, and so on in painting, or the use of alliteration and rhythm in poetry) but distinguishes this from *aesthetic pleasure.* Similarly, although we can take pleasure in the content of a work alone—say, considering *Madonna and Child* beautiful because it depicts motherly love—this would not constitute *aesthetic pleasure* in this view.

relation between form and content—and what falls under each category—can vary. Consider, for example, Lamarque's distinction between different levels of content, or the "aboutness" of a work. The first is content at the thematic level. This involves the more general, overarching reflections that go beyond the events described in the text, such as the themes of loss or motherhood in *Beloved.* The second is content at the immediate level, which includes the particular events that occur in the novel. Although Levinson and Lamarque differ here, Lamarque similarly states that the thematic content (what Levinson just labels as "content") shapes the choices regarding the particularities of the narrative; it is the "perspective or vision or general reflection that informs the subject matter and moves beyond the immediate events portrayed" (2009, 150). I come back to these differences in the next section.

Carroll offers a similar view to Levinson. He characterizes the form of an artwork as "whatever functions to advance or to realize whatever the artwork is designed to bring about. The form of an artwork is what enables the artwork to realize its point or its purpose" (1999, 142). Carroll's view entails that artworks have a purpose or have a point to make, but he emphasizes that this should be understood in a broad sense. A purpose of an artwork could be to arouse certain feelings or responses in the audience, to advance a particular point of view or to communicate an idea, to explore a theme, and so on. Additionally, a particular work of art can have more than one purpose or more than one point to make. In Carroll's view, then, our analysis of artworks depends on having a conception of the point(s) or purpose(s) of the work. We will see that in the case of thought experiments, too, our aesthetic analysis, conceived in this way, is dependent on what the example is being used for. Carroll highlights that in the case of artworks, there will be variation with regard to how easy it is to determine the point(s) or purpose(s) of a work. He notes that this is why "formal analysis also usually comes hand-in-hand with interpretations or explications of the work" (1999, 145).[10]

Carroll focuses on the point or purpose of an artwork rather than the content of an artwork because he is also interested in artworks that do not have content, such as much orchestral music or "pure dance." Given that my focus is on thought experiments, which are clearly *about* something (i.e., they have content), I will not go into the details of Carroll's discussion here and will instead just note that for him, the "point or purpose" of a work is a larger category that includes content.[11]

As with Levinson's view, this relation between form and content is part of our aesthetic appreciation of artworks. Carroll states: "What we appreciate in an artwork is how the forms function as means to bring about the ends of the artwork. Where these forms are well suited to the ends of the artwork, we generally take satisfaction in their design" (1999, 150). Now that we have a sense of the importance of form and

[10] Egan (2016) and Frigg and Nguyen (2017) both use the topic of interpretation as a way of highlighting a difference between artistic and scientific representations. The thought is that unlike artworks, models and thought experiments cannot be interpreted in a "flexible" way. This is an interesting topic, but because this does not hinge on my focus here, I'll just note that while there are limits to how a thought experiment can be properly interpreted, there can be disagreements regarding what would happen in the scenario presented or what conclusions can be drawn, and thought experiments can be analyzed from the perspective of different theories (see Bokulich 2001, Elgin 2017, Murphy 2020a).

[11] See Carroll (1999, chap. 3, part II) for discussion.

content in the aesthetic appreciation of artworks, I will turn my attention to the relation between form and content in thought experiments.

4. The formulation of thought experiments

In this section, I will demonstrate that the usefulness of a thought experiment in scientific practice is affected by the way in which its content is conveyed. What do I mean by the formulation of thought experiments? To see this, we should first note that thought experiments are ultimately concerned with abstract ideas that can be generalized beyond the particular details of the thought experiment narrative (Egan 2016). For example, in Galileo's falling bodies thought experiment, Galileo is interested in exploring the relation between the weight of a body and the speed at which it falls. I take this to be the content of the thought experiment.

The form of Galileo's thought experiment includes the way in which the relation between speed and weight is expressed through the particular events and objects used in the scenario—that is, the bodies being dropped from a height, such as the musket ball and the cannonball, as in Brown's presentation of the thought experiment outlined earlier. In a common textbook formulation, the thought experiment describes dropping the bodies from a particular height, namely, the Leaning Tower of Pisa. This detail appears to derive from a biography of Galileo, written by Viviani, that describes Galileo performing the experiment from the top of the tower, in front of a crowd of students and academics who watch from below (Segre 1989). In his own writings, Galileo seeks to show how "a cannon ball weighing one or two hundred pounds, or even more, will not reach the ground by as much as a span ahead of a musket ball weighing only half a pound, provided both are dropped from a height of 200 cubits" ([1638] 1914, 62). Yet he formulates the actual thought experiment differently, beginning with the following statement: "if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight" ([1638] 1914, 63).[12]

As with artworks, I argue that a source of the aesthetic value of thought experiments comes from the manner in which their formal features function as a way of bringing about their content. When the form is well suited to the content of the thought experiment, we may regard it as aesthetically valuable. Thus, although we could take pleasure in the content of, say, Galileo's falling bodies or in a thought experiment's formal features alone, what I am interested in here is how the interrelation of these two aspects of a thought experiment is a source of aesthetic value.

As noted, the relation between form and content can be complicated when we introduce Lamarque's (2009) distinction between two levels of content: the thematic

[12] Despite these variations, it seems uncontroversial to say that these all count as the same thought experiment. This is because, perhaps, they all formulate the content—the relation between the weight of a body and the speed at which it falls—in a similar way; they all describe dropping objects of different weight from a height. This clearly differs from the examples presented by Darwin discussed later in the article, which have more significant differences in form and count as two different thought experiments. It would be interesting to explore questions of the identity of thought experiments in light of the form–content distinction offered here, but this will have to be left for another time. See Bokulich and Frappier (2018) for an outline of the variety of views available on the identity of thought experiments.

content and the immediate content. In the case of *Beloved*, we saw that the particular events described count as part of the immediate content of the work, and the themes of loss and motherhood count as part of the thematic content of the novel. We can apply this to thought experiments in science, too. The tower and the balls or stones and so forth in Galileo's thought experiment would also be part of the immediate content of the example. In contrast, in Lamarque's distinction, the relation between speed and weight is part of the thought experiment's thematic content: it is the overarching content that goes beyond the particular details of the narrative. As with the case of novels, this overarching content informs the choices made at the level of immediate content.

Whether or not we want to label what I am interested in as a relation between two different levels of content or as a relation between form and content is an interesting question. However, the important aspect for my account is that we have this relation between two things—between the (thematic) content and how that is expressed in the particularities of the example. I will therefore stick to Levinson's and Carroll's ways of drawing the distinction as presented in the previous section, but I will note that this implies that choices regarding narrative content can count as part of the form of a work. If the purpose of a thought experiment is to, for example, convince us of something or explain some idea, then the form comprises the choices made to realize that purpose, including those at the level of narrative content.

To see this distinction in more detail and to see the epistemic payoffs of this "fit" between form and content, I'll now compare two examples of thought experiments, or "imaginary illustrations," from Darwin. Darwin invoked these illustrations throughout *On the Origin of Species* in order to, as he puts it, "make it clear how, as I believe, natural selection acts" (1859b, 90). As Lennox explains, Darwin uses thought experiments to demonstrate the explanatory potential of the theory of natural selection—that the theory can explain a range of phenomena—rather than to provide evidence of its truth (1991, 223).[13]

The first illustration, presented earlier, is the whale thought experiment. Picking up on Darwin's description of a "monstrous whale," Agassiz described the thought experiment itself as "truly monstrous" (Stuart 2016b, 31). Others had a similar reaction. In Darwin's letters, we can see that the example caused controversy. Darwin explained that the thought experiment was intended to show how selective pressure could lead to the widening of the bears' mouths, but some had taken it as intending to convey that the mouths could widen over time due to bears using their mouths to catch insects. Darwin labeled this a "grave misapprehension" of his view (Darwin 1860b). In a review of *On the Origin of Species*, anatomist and paleontologist Owen ridiculed the example, stating, "we look ... in vain for any instance of hypothetical transmutation in Lamarck so gross" as the bear–whale (1860, 518). Yet in discussions with Darwin, he also noted that the passage had stood out to him. Darwin explained in a letter to Lyell that Owen had also misunderstood the example, taking it to state that it was attempting to show how a bear could become a whale, or as Darwin puts it, how

[13] See also Schlaepfer and Weber (2018) and Love (2010) for a discussion of Darwin's thought experiments.

"a sort of Bear was the grandpapa of Whales!" (1859a). Elsewhere, Darwin remarked that the thought experiment had been "well laughed at" (Darwin 1860a).[14]

There are multiple ways in which we can think about the aesthetics of this example. One way is to consider the imagery that the thought experiment produces; the image of the bear's mouth becoming wider and wider is peculiar and perhaps even ugly. And so, the thought experiment could be considered "monstrous" in this sense.[15] A related way is that, because of the bizarreness of the bear–whale imagery, the thought experiment can be considered captivating. This might accord with how the passage was "gross" to Owen yet also stood out to him. An analogy of this in the case of art is instances of "good–bad" artworks, as discussed by Dyck and Johnson (2017). In such cases, the artistic failure of such works makes them bizarre, which, it is argued, is aesthetically valuable. As Walton states, we enjoy "something like awe and amazement at how awful the thing turned out to be *despite* the efforts of its creators" (2008, 21).[16]

However, another way to think about the thought experiment's aesthetic value is to focus on the relation between the thought experiment's form and content. And it is this way, I argue, that is relevant to its epistemic value. To do this, it is helpful to compare the thought experiment with another of Darwin's imaginary illustrations: the eye. Darwin was not concerned with explaining how the eye actually evolved; the illustration was used to demonstrate the explanatory power of his theory—in particular, how spontaneous mutation and natural selection could conceivably bring about an organ as complex as the eye. In addition, he sought to explain how every slight change in the development of a complex organ or behavior could bring about something more advantageous than the previous stage (Lennox 1991, 238; see also Stuart 2016b). In the 1872 edition, he states: "To suppose that the eye with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest degree" (Darwin 1872, 143). The thought experiment is outlined as follows:

> [W]e ought in imagination to take a thick layer of transparent tissue, with spaces filled with fluid, and with a nerve sensitive to light beneath, and then suppose every part of this layer to be continually changing slowly in density, so as to separate into layers of different densities and thicknesses, placed at different distances from each other, and with the surfaces of each layer slowly changing in form. Further we must suppose that there is a power, represented by natural selection or the survival of the fittest, always intently watching each slight alteration in the transparent layers; and carefully preserving each which, under varied circumstances, in any way or in any degree, tends to produce a distincter

[14] See also Beer (2000, 98) for an outline of the reception of this thought experiment.

[15] Similarly, Einstein's light-beam thought experiment might be considered aesthetically valuable due to the beautiful mental imagery of chasing a beam of light that the example prompts us to have.

[16] Examples of "good–bad" art, as discussed by Dyck and Johnson, include the 2003 film *The Room*, which is "a confusing mix of a bizarre storyline, terrible acting, very little plot cohesion, and a script that consists almost exclusively of clichés. But this mix makes for an enjoyable film" (2017, 279).

> image. We must suppose each new state of the instrument to be multiplied by the million; each to be preserved until a better one is produced, and then the old ones to be all destroyed. In living bodies, variation will cause the slight alterations, generation will multiply them almost infinitely, and natural selection will pick out with unerring skill each improvement. (Darwin 1872, 146)

Stuart discusses these two examples and argues that the eye thought experiment is successful, whereas the whale example fails. As mentioned, Darwin used his imaginary illustrations with the aim of showing the explanatory power of the theory of natural selection. And Stuart highlights that the two thought experiments are functionally similar. In each, Darwin is attempting to explain how a complex part of nature could have come about through a series of steps (Stuart 2016b, 31). We can label this the content (or, in Lamarque's view, the "thematic" content) of Darwin's two examples.[17] Although the two examples involve different applications—the intricacies of the eye and the morphology of whales—each is used to show how the theory can account for a variety of natural phenomena.

How does this source of aesthetic value affect the epistemic value of a thought experiment? In the next section, I'll set out an answer through a consideration of scientific understanding and the connection between thought experiments and their use of the imagination.

5. Aesthetic value and understanding

Scientific understanding is a central topic in the philosophy of science, and the literature has expanded significantly in recent years. The way in which thought experiments contribute to understanding has been largely ignored, and the focus has been primarily to do with how they produce knowledge (although see Stuart [2016b, 2018], Elgin [2017], and Meynell [2018] for discussions of thought experiments and understanding). Additionally, there are many complexities in the literature on understanding, and various questions make up the debate—for example, whether or not understanding is ultimately a type of knowledge or whether it is distinct, and whether factivity is a condition of understanding. Here, I want to focus on a particular aspect of the scientific understanding literature, and this concerns the idea of "grasping." Although my discussion is limited to just a few accounts, my aim is to indicate the way in which aesthetic value has epistemic force in the case of thought experiments and show that this could also be generalized to other features of scientific practice.

It is often stated that understanding requires something over and above merely believing or knowing some information. This extra requirement is commonly articulated in terms of being able to "see" or "grasp" how the different parts of information relate to each other. For Grimm, grasping involves being able to "see" or anticipate how changing one part of a system would affect the system overall, as well as being to apply some theory or principle to different situations (2010, 340–41). And de Regt argues that understanding some phenomenon requires the grasping of a

[17] This means that in Lamarque's view, as discussed earlier, the particular events described—the bears and whales or the stages of eye development—would count as the immediate content.

scientific theory. The key notion for de Regt is "intelligibility"; this is "the value that scientists attribute to the cluster of qualities of a theory (in one or more of its representations) that facilitate the use of the theory" (2017, 40). The grasping of a theory of a phenomenon consists of being able to use the theory to give explanations about some phenomenon. Hills (2016), Elgin (2017), and Wilkenfeld (2013) also offer ability-based views of understanding. Although there are differences across these views, there is an agreement that understanding requires being able to *do* things with information rather than just accepting or knowing it.

What is especially pertinent about de Regt's view is that he is explicit in providing a role for imagination in his account; one of the qualities included in the cluster of features that contribute to the intelligibility of a theory is visualizability. He argues that a sign that some theory has been grasped is that "one has developed a 'feeling' for the consequences of the theory in concrete situations" (2017, 102). Although there is clearly more to be said on ideas of "seeing" and visual mental imagery in understanding, here I consider the imagination more broadly to include both the sensory imagination, including visual mental imagery, as well as the propositional imagination (i.e., imagining *that* something is the case).[18] I agree with de Regt that visualization can be a helpful tool in understanding, but the important point for my purposes is how understanding can be aided by imagining concrete scenarios. Thought experiments allow us to work through an idea and explore the implications of a theory in concrete cases. In doing so, they can enhance the "intelligibility" or "usability" of a theory. This aim of thought experiments can be seen in the examples outlined previously: Darwin applies his theory to vivid, concrete processes to provide what Lennox describes as a "feeling of experimentation" (1991, 229). Further, although Darwin is interested in explaining how the theory of natural selection can account for the complexity of the eye and the morphology of whales, his imaginary illustrations are also used to illuminate the theory in such a way that it allows those who engage with the examples to grasp the theory. This includes gaining an understanding of how the illustration can provide possible explanations for other complex organs and species. With this in mind, we can see how the formulation of Darwin's examples affects their effectiveness in increasing the understanding of natural selection.

Darwin's whale thought experiment can be easily misinterpreted. In explaining how whales could have evolved, Darwin chooses to invoke an existing animal. This makes the example more convoluted than is necessary and makes it difficult to focus on the key features of the example—the step-by-step changes of a species that result in it becoming something else—and instead can easily lead the reader astray. For example, the reader considers the bear as integral to the example and thus concludes

[18] For more on the type of imagination in scientific thought experiments and models, see Salis and Frigg (2020) and Murphy (2020b). Meynell (2020) discusses the role of visualization and pictures in understanding, arguing that understanding is a case of "getting the picture." Breitenbach (2020) links scientific understanding and aesthetic experience via the imagination, but because she is concerned with demonstrating how experiences of beauty and gaining understanding utilize the same types of imaginative activities, her aim is orthogonal to mine here when it comes to the connection between understanding and aesthetic value. I do, however, agree with her claim that the imagination can aid the achievement of unification, which she takes as fundamental to understanding. A focus on understanding (as opposed to knowledge) in the aesthetics in science can also be seen in the work of Ivanova (2017a).

that the thought experiment is trying to show how whales could evolve from bears. This is a stark contrast to the eye illustration. In this example, we are given a solution to the problem of the "absurdity" of the prospect of natural selection accounting for intricate phenomena through the description of the eye. Because of the way the thought experiment formulates its content, the example is easy to imagine. Starting from just a nerve that is sensitive to light, we see how various alterations (e.g., changes in the density and thickness of tissues and the shape of the surface of the eye) lead to an increasingly complex organ that, at each stage, produces a better image. Further to this, the description offered gives the reader a way of going beyond the particulars of the case. The clarity of the example means that engaging with the thought experiment enhances our ability to apply the process of step-by-step changes to the evolution of other complex phenomena (Stuart 2016b, 30).

In his discussion of the role of metaphors in scientific understanding, Levy argues that metaphors work by engaging the imagination. He discusses how a good metaphor should represent the relevant facts in a useable way; metaphors "frame" their targets by directing attention in a way that is "striking and illuminating" to particular properties of their target subject via a more familiar subject matter. This allows us to use existing cognitive resources to understand a new, unfamiliar target system (Levy 2020, 293; see also Camp 2009). Similarly, in thought experiments, the way in which they are formulated via the particular fictive events described—often familiar objects, such as the balls or stones and towers in Galileo's example—are used in order to realize the more general, abstract content. Thought experiments can also be presented alongside analogies. Just before the passage describing the eye quoted earlier, Darwin draws on readers' knowledge of how telescopes have been "perfected by the long-continued efforts of the highest human intellects" and states that we can see how eyes and other complex natural features could have evolved in an analogous way (1872, 143; see also Stuart 2016b, 29).

Although I have focused on the form–content distinction in the case of thought experiments by drawing on discussions of literary works in the philosophy of art, I hope that this opens the way for a further investigation into the ways in which models and diagrams (i.e., nonlinguistic representations) also present their content and how this can both be a source of aesthetic value and have epistemic relevance. A place to start might be the work of Vorms (2011) and Meynell (2015). Vorms sets out to show that capturing the "representational power" of models requires focusing on the "cognitive interactions between agents and the representational devices they reason with and manipulate" (2011, 288). Vorms demonstrates that the way in which information is formulated is crucial to these interactions. Take the case of representing the results of a temperature survey. These results are represented in different ways, as a list of numerals and on a map. Although it is the same information in each representation (i.e., the same content that is being conveyed), Vorms argues that "the map makes some information much more easily available: for instance, if warm shades stand for high temperatures and cold shades for low temperatures, one can quickly conclude that the southern part of the represented area is warmer than its northern part" (2011, 289). Drawing this from a list of numerals that stand for the coordinates of the place and its temperature value would involve many inferential steps (Vorms 2011). Meynell (2015) discusses the ways in which scientific images

represent their content (compared to natural languages and mathematics), drawing on Goodman and Walton's work on artistic representations to do so.[19]

Vorms highlights that the most appropriate format can depend on the particular interests and skills of those engaging with the example. The significance of how the content of a thought experiment is formulated, or what counts as the best formulation, might also vary depending on certain contextual features. Stuart takes the whale thought experiment as a failed thought experiment, arguing that it does not increase understanding. I agree that the thought experiment has problems and can easily lead to confusion (as it clearly did at the time) regarding what Darwin was trying to explain. Although Darwin removed the thought experiment from later editions due to the backlash that he received, he stood by its potential explanatory power. I think it is possible that the thought experiment could aid our understanding of natural selection, but it is far less apt to do so than the eye example. Hence, this affects its usefulness as a thought experiment for Darwin's purposes. In *On the Origins of Species*, Darwin was appealing to a broad audience, and similarly, when presenting his falling bodies thought experiment, Galileo was communicating with not only a scientific community but also a public one. The particular ways in which the scientific content is expressed through the formal features of the example are thus chosen with certain audiences in mind; the success of the thought experiment ought to be measured against who the example was designed for. This also means that although someone who may be familiar with the theory of natural selection could perhaps navigate Darwin's whale example, someone less familiar with the theory is more likely to get confused by the case, and hence it will not enhance the usability of the theory of evolution by natural selection.

6. Conclusion

I began with a dilemma facing those who seek to defend the role of aesthetic values in science. The issue is that either aesthetic terminology in science is used in merely a metaphorical sense (and really tracks epistemic features), or scientists' aesthetic responses are genuinely aesthetic, but such values do not form an important part of science. I have presented a new way of considering aesthetic value in the scientific domain by turning to views arguing that a source of aesthetic pleasure in artworks has to do with the relation between the content of a work and the way in which it is formulated. I outlined how the fit between form and content in thought experiments plays a significant role in their usability in science. To show this, I discussed two examples from Darwin that are used to demonstrate the explanatory power of the theory of natural selection. The way in which these examples are formulated—that is, the way in which their overarching content is expressed—helps explain the success of the eye thought experiment and the failure of the "monstrous" whale example in increasing the understanding of natural selection. A fit between form and content enhances the accessibility of a thought experiment—and hence its usefulness as a prompt for our imagination—and plays a role in aiding our understanding of some theory or phenomena.

[19] See also Meynell (2018) for a discussion of the ways in which thought experiments are often presented alongside images and an analysis of why presenting the content of certain types of thought experiments pictorially is useful to their role in science.

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