**Imagination, Aesthetic Feelings, and Scientific Reasoning**

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**Abstract**

The present chapter focuses on the role of imagery in scientific reasoning. The main questions to be considered, are: 1) what role does visualisation play in scientific reasoning? and hence 2) what epistemic credentials, if any, does visualising have in scientific reasoning? In addressing these issues, we will look at fictional accounts of scientific models, the transparency of imagining, and the nature of epistemic and aesthetic feelings. In brief, two key moves need to be made to secure the epistemic standing of sensory imagining in science. First, in exploring the differences between the transparency of perceptual and imaginative experiences, we need a proper appraisal of the relationship between sensory imagining and affect, and in particular the affective feelings that are manifestations of aesthetic experience. Second, we need to focus our attention on the notion of understanding, rather than truth or knowledge.

**Introduction**

Nobody denies that thought experiments (TE) and scientific models (SM) play a crucial role in scientific reasoning. Further, it seems undeniable that TE and SM centrally involve the imagination. It is, however, in considering the nature of this involvement that a series of questions and problems arise. Many of these are epistemic: given the kind of activity imagining is, how could it possibly help to reveal empirical facts about the world? How could scientific beliefs formed via imagination possibly be justified? Some questions, however, are non-epistemic: what is a scientific model? What sorts of imaginings are involved in TE and SM? What exactly is the imagination? Clearly, answers to the epistemic questions depend in part on the answers to the non-epistemic questions. Yet these latter questions seem so difficult, and the various available answers so inconclusive, that the enterprise of understanding the nature of TE and SM, and hence the role of imagination in scientific reasoning can appear impossibly daunting.

In order to make these issues a little more tractable, the present chapter will focus primarily on just one form of imagining involved in TE and SM, the kind that is essentially imagistic and is often called ‘visualisation’. The main questions to be considered, then, are: 1) what role does visualisation play in scientific reasoning? and hence 2) what epistemic credentials, if any, does visualising have in scientific reasoning? As we shall see, however, addressing these issues will involve saying quite a bit about how visualisation – which I will also refer to as ‘sensory imagining’ – relates to non-imagistic propositional imagining. In short, the connection between imagination and feeling (or ‘affect’) is central to understanding the cognitive value of SM.

Two further qualifications: I will only be concerned with theoretical and not physical models, and I will understand SM as being a type of TE. I do not deny that the success of some SM is independent of any visualisation that may take place. I will argue only that visualisation, and other types of imagery, can play a crucial epistemic role in SM. There may be good reasons to distinguish TE from SM, but I suspect that visualisation plays the same sort of epistemic role in each. For this reason, unless I refer to them explicitly, I will often talk of the role of visualisation in ‘scientific reasoning’ and I will take it that the conclusions reached can apply equally to SM also to TE.[[1]](#footnote-1)

Although some philosophers have denied that imagination plays an important role in scientific reasoning, many philosophers have come to accept that it does, and several have recently defended the epistemic value of imagining in SM. Nonetheless, it is fair to say that with few exceptions the role of imagery has been entirely downplayed – a mere psychological embellishment that itself does no epistemic work – or regarded with deep suspicion. Yet, surprisingly, philosophers working in this area generally have little or nothing to say about the nature of imagery. I do not think that the role of imagery in scientific reasoning can be so easily ignored, and my main goal will be to show how visualisation can play an important epistemic role here. Indeed, I shall argue that current accounts of SM that rely solely or primarily on non-imagistic imaginings fail to account adequately for their ineliminability and success in scientific reasoning. The way ahead will, though, be a little convoluted, because consideration of the relatively *non-transparent* nature of images poses a serious problem for the idea that visualising could possibly offer any epistemic insight into physical phenomena.

In brief, two key moves need to be made to secure the epistemic standing of sensory imagining in SM. First, in exploring the differences between the transparency of perceptual and imaginative experiences, we need a proper appraisal of the relationship between sensory imagining and affect, and in particular the affective feelings that are manifestations of aesthetic experience. Second, we need to focus our attention on the notion of understanding, rather than truth or knowledge.

**I. Fiction and Scientific Models**

The most prominent current views of SM that acknowledge the central role of imagination appeal to our engagement with fiction in order to illuminate this role. Toon (2016) helpfully divides such ‘fictional’ theories into Direct and Indirect. The latter are indirect in the sense that they require us to think of SM as like a work of fiction, or a fictional world, which we examine in order to find out what its properties are and which we then apply to the real world, of which it is a representation. The indirect view assumes, then, that the properties of SM go beyond those that are explicitly specified in the description of SM, and that these properties can be used to give insight into the real world in virtue, somehow, of representing it.

The most comprehensive attempt to explain how this is possible is given by Roman Frigg (2010a; 2010b), who appeals to Walton’s well-known theory of fiction as make-believe. For Walton, fictional representations are *props* in games of make-believe; that is, fictional works (qua games of pretence) prescribe us to imagine certain things, in line with the propositions explicitly given in the work (the description of the game world), but also in accordance with certain *principles of generation* that constitute the rules of the game. Notoriously difficult to articulate precisely or fully, principles of generation will normally include, for example, and unless stated otherwise, a ‘reality principle’, such that for the situations and events not explicitly described in the work, we are to imagine that the world of the work operates more or less as the real world does. For instance, if Sherlock Holmes is described as travelling to Dorset, we are not supposed to imagine that he got there by hovercraft. We are supposed to imagine that the city he lives in is just as Victorian London would have been at the time, and so on. Thus, if a proposition is prescribed to be imagined in a game of make-believe, then it is fictional in the relevant game i.e. ‘true in the fiction’. Frigg’s idea then is that SM are props in games of make-believe.

When we read the model description for the Newtonian model of the solar system, Frigg states, “we imagine an entity which has all the properties that the description specifies. The result of this process is the *model-system*, the fictional scenario which is the vehicle of our reasoning: an imagined entity consisting of two spheres, etc.” (2010b: 133) After imagining her model system, the scientist goes on to connect it to the real system. In this case, for example, she might specify that “the sphere with mass *me* in the model-system corresponds to the earth and the sphere with mass *ms* to the sun’ (2010b: 134). Once this is done, she can “start translating facts about the model system into claims about the world” (2010b: 135).

The Direct Fiction view also draws on the Waltonian framework of make-believe - model descriptions are ‘props’ in a game of make-believe that prescribe imaginings about reality – but employs an analogy with fictions about real world events and characters, rather than fictions *tout court*. As Toon (2016) says of his own position, the main contrast with the Indirect view is that his does not posit any model systems representing the real world. Rather, scientists represent the world directly, by asking us to imagine things about it:

 “In this approach, learning about a model is not a matter of discovering facts about an abstract or fictional model system; it is a matter of exploring the web of imaginings prescribed by a scientist’s model description. For example, the Newtonian model description asks us to imagine that various assumptions hold of the sun and earth, such as that the force between them obeys Newton’s law of gravitation. If we accept these initial assumptions, however, we are also to imagine that the earth moves in an ellipse, since this follows from the equation that we write down. This is simply part of the conventions that govern our interpretation of model descriptions. That the earth moves in an ellipse is therefore part of the content of the model, even though this was not specified in the model description.” (459)

Whatever its other advantages (e.g. explaining scientific discourse), if we focus solely on the ability of models to provide information about empirical reality, the positing of a representation between us and reality by the indirect model seems problematic, not least because the mechanisms by which we get from the properties of the model to the real world properties the model supposedly represents is obscure. In order to see this, we must recognise a problem that each of these views share; a problem inherited from the Waltonian model on which they both rely.

The Waltonian framework of fictional engagement might seem to be initially appealing as an analogy for understanding SM, insofar as it offers certain plausible constraints on appropriate ‘make-believe’, constraints that govern, in part, the ‘fictional’ truths implied by/contained within SM. Yet, the lack of detail concerning the crucial elements of the view is, I think, sufficient to threaten the plausibility of the above aa abccounts.

In both fictional accounts of SM we have a) a set of descriptions that give the bare content of the model, b) principles of generation that allow us to go beyond such descriptions to posit properties that will be true according to the model and c) by some process of inference, perhaps resemblance in the case of indirect fictions, a ‘mapping’ from these properties to those of the real world system we are representing/imagining. To take an example from Toon’s account: a model of the ideal pendulum is a description that prescribes us to imagine that the target, the real ball and spring system we have in front of us, is exactly as the text presents it: we have to imagine the spring as perfectly elastic and the bob as a point mass. So, SM are types of surrogative reasoning that allow us to learn about the target system via principles of generation that constrain what we are to legitimately imagine about the target system. But what are these principles and where do they come from? What justifies the choice of some rather than others?

In an attempt to answer these questions, Salis and Frigg (2017) contend that, to be successful, SM must be constrained at least by a reality principle (of the kind noted above) as well as a ‘mutual belief’ principle, a principle directed towards the mutual beliefs of the members of the community in which the story originates. They state:

“While these principles can be at work in certain TEs or SMs, other options may be possible.

Meynell (2014, 4162-3) points out that different kinds of TEs make use of different principles, and which ones are chosen depends on disciplinary conventions and interpretative practices. Specifically, she points out that ‘which principles of generation a physicist brings most automatically to a TE will tend to reflect her beliefs about reality as well as the various theories and projects upon which she currently works’ (ibid., 4163). For this reason, neither the reality principle nor the mutual belief principle are in any way privileged and different principles may be

needed in specific domains of scientific enquiry.” (22)

This, it must be admitted, is not very informative, but perhaps the variable nature of the contexts here makes further general context-independent specifications impossible. Nonetheless, it seems evident that in the case of SM, principles of generation must come from current (scientific) beliefs about how the world is – specifically those concerning the relevant domain of investigation – and the various background theoretical assumptions and explicit theories of which the experimenter is aware and which the experimenter thinks applicable to the model she is working with. Where else could they come from? Any given set of principles must, obviously, be chosen prior to the formulation of the SM. They are clearly not discovered in the model because, recall, anything discovered in the model is a *product* of prior principles and explicit descriptions. But now, it is very difficult to see what epistemic work could be being done by the imaginative engagement with the model, since the imaginings are constrained prior to such engagement. What could we possibly learn from the model that we didn’t put into it in the first place? And even if it did seem to us that certain properties of some phenomenon were ‘revealed’ in engaging with the model, at best that is a contingent product of the principles we chose in advance. What if we had chosen different principles?

Now, one cannot pretend that these observations by themselves undermine the fictional view of SM, and as we will see, I will go on myself to argue that the imaginative engagement present in SM is of cognitive value. Yet they do, I contend, reveal that all of the work in explaining the appeal to fictional make-believe, and justifying its epistemic value in scientific reasoning has still to be done. The appeal to Waltonian games of make-believe by itself throws little light, if any, on the cognitive value of SM or the epistemic function of imagination therein.[[2]](#footnote-2)

One might suspect that part of the problem here consists in the view of make-believe being offered. Salis and Frigg are explicit that the epistemically operative imaginative activity involved in SM is propositional imagining rather than sensory imagining. We ‘entertain’, rather than commit in a belief-like way to some proposition *p* or set of propositions that may or may not be accompanied by imagery, which itself plays no cognitive role in SM. If SM involve an imaginative engagement only with propositions – including descriptions, diagrams, and formulae – then the scepticism I just outlined seems inevitable, although it does perhaps still allow for SM to possess a surrogative role in scientific reasoning, just not one in which make-believe as such plays any interesting or substantive role.

So, in this light, it is imperative to ask: why the insistence on propositional imagining? Salis and Frigg (p.17) argue that imagery is neither necessary nor sufficient to the outcome of scientific thought experiments. They state that “not all factors that matter to the successful performance of a TE seem to have sensory-like correlates. When considering Galileo’s cavity we do not seem to have a perception-like representation of the cavity being frictionless or the lack of air-resistance.” Imagery is not necessary since the cognitive work is done by the descriptions, concepts, and mathematical formulae of which the SM, qua SM, entirely consist.

“we cannot form a perception-like representation of the concept of force without having a theoretical definition, which is usually given in linguistic and formulaic symbols. Similarly, Malileo’s SM assumes these concepts, but he also requires theoretical knowledge of Lagrangean mechanics, general principles and laws, mathematical abilities, and logical inferential abilities… We need to grasp the relevant concepts, with or without forming a mental image of the objects and transformations they stand in for”.

At root here is, I think, a fairly familiar account of the uselessness of imagery, the thought that the relationship between a mental image and what it represents is determined by a description or interpretation, and not that of any resemblance between the image and its objects. That is to say, the intentionality of images is determined by the intention of the agent in forming them, and not by the intrinsic properties of the image as such. This feature of images explains what has been termed the ‘multi-use’ thesis, namely that the same image can stand in for many different imaginings (or imaginative projects), and that an imagining’s success conditions do not – at least not solely – depend on the features possessed by the accompanying imagery. For example, suppose that my aim to imagine a chiliagon involves an image of a figure that does not literally have a thousand sides. The relatively impoverished nature of this image does not, it seems, undermine my imaginative project. Indeed I could also use the very same image to successfully imagine a hundred-sided figure.[[3]](#footnote-3)

It is perhaps interesting to note the relationship between this claim and my objection to the principles of generation view above, that you only get out of an imagining, or image, what you put into it. Traditionally, many philosophers have held that images are essentially uninformative since their content is wholly determined by our intentions. From this fact follow other purportedly essential features of imagery, such as their inability to allow for genuine observation, in the sense that, unlike the objects of perception, we cannot discover new features or hidden aspects of the objects we imagine, nor are there any features of an imagined scene of which we are only peripherally aware. Images are, the thought goes, wholly sustained by attention and there is thus no equivalent in imagery of the centre and periphery of awareness that we have in the visual field. (See McGinn 2006) Imagining is in these ways essentially intentional, and in the context of gaining knowledge about the world, imagery is at best a merely psychological heuristic aid. As such, there is no obvious way in which it could play a genuine cognitive role in informing us about reality. We will return to these issues below.

In order to consider whether this view of imagery is accurate, it will be helpful to consider an issue that is not often discussed, and certainly has not been in the context of this topic: the transparency of imagery. I will argue that the non-transparency – or relative ‘opacity’ – of imagery is what allows it to play a significant cognitive role in scientific reasoning.

**II. Imagery and Transparency**

Given the above observations, it is difficult to see how visualisation itself could play a useful explanatory role in scientific reasoning. Rather, the role for visualisation is at best merely heuristic, a view supported by the purported fact that our imaginings are not directed at images themselves but at the ‘things’ the image is of. The intentional object of imagining, it seems, is not images. Images are merely, in the words of Kind, a type of ‘mental paint’ with which the imagination takes its intentional objects, the objects that are imagined. This is one sense, it might be held, in which images are *transparent* to the objects of imagining. We employ images to help us imagine but we – so to speak - see right through them to the things we are actually imagining. As such, it might seem, imagination in SM can successfully latch onto the physical world that is the main target of SM via images. Call this feature of images their ‘transparency-to-the-world’. This clearly fits quite nicely with the Direct Fiction view, and it does not seem to pose a prima facie obstacle either to the Indirect View. But let us first look more closely at the notion of transparency.

There are various formulations of transparency, and the notion has traditionally played a central role in representational theories of perception. Here are two formulations of transparency adopted and adapted from Matthew Soteriou (2010)

**Strong Transparency:** introspection of one’s perceptual experience reveals only the objects, qualities, and relations one is apparently perceptually aware of in having the experience.

**Weak Transparency:** when one introspectively attends to what it is like for one to be having a perceptual experience, it seems to one as though one can only do so by attending to the sorts of objects, qualities, and relations one is apparently perceptually aware of in having that experience.

It is, unfortunately, not obvious exactly how one can apply these ideas to imaginative experiences.

This is because imagination is phenomenologically unlike perception in being a threefold relation – attitude/experience, imagery, world (as imagined) – and this is so even where representationalist theories of perception posit representational content, because the conscious awareness of imagery in imaginative experience has no direct equivalent in perceptual experience. So, for example, it is not clear whether, if we transpose these views about transparency to the imagination, the ‘objects’ of which one is aware in imaginative experience are to be thought of as images, or the ‘real’ intentional objects of the imaginings (which we imagine via imagery). It is also not clear whether an imaginative experience that involves imagery is to count as an experience of the imagery or not.

If images are transparent in the sense outlined above, then imaginative experience must, one might think, be transparent to the objects (i.e. not images) that are imagined. But, of course, this seems wrong insofar as we are generally aware of our imagery when, for example, visualising, and such an awareness does not seem to depend on paying attention to the intentional objects of images, which would be required if images were strongly transparent to their objects. Would it be accurate to say that imaginative experiences are transparent to images, and then somehow transparent to the world via the transparency of imagery? I do not think so, since it does not seem to me that either type of transparency applies easily to imaginative experiences. This is for a number of reasons.

When we introspectively attend to our imaginative experiences, in the normal case we are aware of them as such – independent of any imagery that might accompany them – and this awareness necessarily involves an awareness of the essentially intentional i.e. voluntary nature of the state we are in. Let us call this ‘phenomenological voluntariness’. We are responsible for, and have some control over, the initiation, continuation, and content of the state. The type of attitude that counts as imagining is one that normally involves some intentional active *effort*. This phenomenology is very different from that involved, normally, in the *passive* state that is perception. So, there are phenomenological, and possibly structural features of an imaginative experience that we are normally aware of simply in virtue of having that experience.

This tells, at least, against imagining being strongly transparent. It seems to leave open the possibility that imagining is, however, weakly transparent since it might be argued that we are aware of these features only by attending to the images of which such experiences consist. Images themselves contain features that seem to be intrinsically linked to this voluntary phenomenology and that also tell against their supposed transparency-to-the-world, even if we acknowledge that imaginings in general are not intentionally directed at images.

Famously, images lack saturation – they do not completely fill in the visualised field in the way that our perceptual field is completely filled in, endlessly detailed and has no gaps in it. If you imagine, say, a landscape or your mother’s face, the level of detail contained in the image seems almost entirely dependent on how much you deliberately add. Unless this effort is made, our imagery is often clearly much less detailed and ‘filled in’ than the equivalent perception would be. Moreover, there is no equivalent in an imagined scene to the (sense of) fullness we are aware of in visual perception. The imagined scene is ‘gappy.’ A related point: images lack determinacy. When imagining a tiger there may be no determinate number of stripes the tiger has, until and unless you deliberately count/add them in your mind. Either as the cause of consequence of such features, images are entirely attention-dependent in a way perception is not. As noted above, there is no equivalent of genuinely observing perceptual objects, of scanning the visual perceptual field, noticing things peripherally and coming to discover, for example, hidden aspects of three dimensional objects.[[4]](#footnote-4)

So, one way of arguing for the weak transparency thesis is to hold that these features of imagery demonstrate that we are aware of the phenomenological voluntariness of our imaginative experiences only in so far as we are aware of these features of imagery. Or to put it slightly differently, we are generally always aware that we are imagining in virtue (in part) of our awareness of the fact that the object of our awareness is an image rather than a percept. [[5]](#footnote-5)

In fact, however, I think this gets things the wrong way around. Phenomenological voluntariness is usually simply a basic datum of our (conscious) imaginative experiences, not one that we need to infer from features of imagery. Images lack determinacy and saturation *because* their nature and content depends wholly on our conscious effort and attention, in a way that is utterly unlike perceptual experience. The fact that we are normally aware that we are imagining, even in cases where no imagery is present, as in propositional imagining, should make this evident. It is phenomenological voluntariness which, I think, ensures that imaginative experiences are not even weakly transparent, whether the objects of such experiences are taken to be images or not.

In this light, it seems that only some type of strong transparency thesis for imaginative experience could accommodate the use of imagery on the fictional theories of SM we have examined. If visual imagery is entirely transparent or plays only a mediating role in SM, then we have a way of understanding how fictional views can safely ignore the role of imagery in SM, because images do not interfere with or pose an obstacle on the path from SM to world. Our imaginings can succeed in latching onto the world as it is imagined as being (either directly or via a representation). Propositional imagining does all the cognitive work and is neither hindered nor helped by any imagery that may accompany it.

If imagining is not even weakly transparent, however, both fictional views would, it seems, be forced to explicitly deny not only that images can play any cognitive role in scientific reasoning, but that where images do feature, they may be detrimental to such reasoning, which is obviously a much stronger claim. The indirect fictional view will, for example, struggle to use a notion of visual resemblance to explain how we latch onto the world via SM, since images differ from their objects in all of the substantial ways discussed above. Relying on them for epistemic guidance would hence be extremely misleading. The direct view also seems forced to deny that any epistemically valid imagining of the world in an SM can rely in any way on imagery. But then it is also difficult to see on this view how we can avoid relying on imagery when we ‘imagine of the world’ where the phenomena we are trying to explain – e.g. the behaviour of gases – are understood in sensory terms. This is because, insofar as the imagination is involved at all in SM it would necessarily be sensory, rather than merely propositional.

On the one hand, these stronger claims about imagery in SM are still compatible with the idea central to both fiction views that all the cognitively valuable work is done by propositional imagining. As such, they raise difficulties only for views that explicitly rely on visualisation to do serious epistemic work in scientific reasoning. On the other hand, however, they seem implausible when considering well-known examples of SM and TE where imagery appears to play a crucial and ineliminable role. Moreover, the essential opacity of imagination, I will argue, is central to understanding the important epistemic value that sensory imagining possesses in scientific reasoning.

**III. Imagery, Aesthetic Feelings, and Understanding**

Let us begin by noting that the multi-use thesis and essentially interpretive nature of imagery – when employed in the service of an imaginative project – do not suffice to undermine the potential cognitive significance of imagery. Imagery is clearly essential, for example, to some judgements of topological similarity, as numerous experiments have shown. (See Gendler 2004)

More importantly, from our point of view, there is reason to think that imagery might possess important cognitive value arising from its connection with certain affective states that themselves possess cognitive import. Tamar Gendler (2004) has argued, citing Damasio’s research, that imaginative rehearsal can bring us to new beliefs that may be unavailable to us if we reason in a disinterested purely hypothetical way. For example, she says, people who are afraid of public speaking or flying can repeatedly imagine themselves performing these activities until their fears are overcome. Note that although visual imagery is clearly at the forefront of this imagining, such a project might also involve proprioceptive and kinaesthetic and other viscerally oriented imagery – such as emotionally-laden memories – that draws on affective elements to increase the power of the visual imagery.

Turning to Mach’s well-known thought experiment designed to show the force required to prevent an object sliding down a frictionless plane, she contends:

“Contemplation of an imaginary scenario (the cut string laid atop the prism) evokes certain quasi-sensory intuitions, and on the basis of these intuitions, we form a new belief about contingent features of the natural world (that the weight of four balls offsets the weight of three balls). This belief is produced not inferentially, but quasi-observationally: the presence of the mental image plays a crucial cognitive role in its formation.” (1160)

It might seem that the role of such ‘quasi-sensory’ intuitions is, however, rather limited in nature and certainly cannot by itself offer the kind of justification that one might seek in scientific reasoning. I will return to this below. Yet for the moment we should note that even if this sort of imaginative reasoning serves a heuristic rather than surrogative function, that is a non-negligible source of some important epistemic value. Despite some warranted scepticism about the analogy between SM and fictions, Currie (2016) suggests that both enable us to see how a system operates under certain conditions: a gravitational system in the one case, a system of interacting persons in another. He cites Catherine Elgin, who argues that both involve simplifying certain patterns of causal interaction, and thereby “select and isolate, manipulating circumstances so that particular properties, patterns, connections, disparities and irregularities are brought to the fore.” (303)

Propositional imaging here does a tremendous amount of work, of course, in setting up the relevant scenarios in imagination and driving the sensory imaginings that follow from it. But I contend that, at least in many cases, the relevant aspects only get highlighted as salient, patterns are recognised, and attention is only successfully focused by an engagement with sensory, imagistic imagining. This is primarily a result of the deep connection between imagery and aesthetic feelings and the epistemic function that such feelings serve in scientific reasoning. I take my cue here from Peter Kosso’s (2002) observation:

‘the hallmarks of scientific understanding are similar to an aesthetic feature associated with literature, music, and the visual arts. It is the feature described as coherence, harmony, and *inevitability of fit.* Aesthetics thus plays an epistemic role in science as an indication of understanding.’(39)

I think it is this connection to aesthetic value, and particularly to aesthetic feelings of the kind Kosso mentions that we need to turn in order to understand the real value of imagery in scientific reasoning. I would like to claim that aesthetic judgements in science are plausibly understood as expressions of what I will call ‘aesthetic-epistemic feelings’ that serve a genuine cognitive and epistemic function. I will propose a naturalistic account of these feelings in terms of sub-personal processes of representing and assessing the relation between cognitive processes and certain properties of the stimuli at which they are directed.[[6]](#footnote-6)

A number of psychologists have recently become interested in a range of phenomena that are usually referred to as epistemic feelings. That is, there are certain quite common affective conscious states, felt to be positively or negatively valenced, that arise in what can be broadly referred to as epistemic contexts. Drawing on a long list compiled by Arango-Munoz and Michaelian (2014), two of the feelings relevant to our present topic would include, for example:

* **The feeling of knowing:** Koriat (2000)= the ‘feeling of knowing’ is in some way a measure of the accessibility of the knowledge one has, correct or incorrect.
* **The feeling of understanding**: A feeling of intellectual satisfaction that motivates the endorsement of an explanation, a sense that we have achieved an understanding of a phenomenon that was not clearly understood before (Gopnik, 1998, 2000; Trout, 2002, 2007). This is sometimes called the “ah ha” feeling (Mangan, 2001) or the eureka feeling.[[7]](#footnote-7)

The primary focus of the psychological literature has centred on the nature and function of such feelings, and whether they are in fact heuristically valuable in assessing the information they seem to concern. Although there is naturally much debate concerning both issues, there seems to be some consensus that epistemic feelings are the valenced experienced manifestation of some kind of quick and dirty, low-level, sub-personal mechanism that monitors the performance of different cognitive processes.  There is evidence for neural correlates of epistemic feelings, and there is evidence that some epistemic feelings do play a justificatory role in, for example, accurately predicting future cognitive performance, and in acting as a stimulus to judgement. [[8]](#footnote-8) In other words, my feeling of uncertainty or of knowing will incline me to (and arguably give me reason to) judge that I really am uncertain or that I do know.

Before looking further at the details, we can note that a few philosophers have also taken feelings seriously as playing an important role in cognition. For example, in discussing the so-called Frame Problem for AI, Ronald DeSousa (2008) argues that feelings and emotions serve to stop the potentially endless regress of deliberation by revealing patterns of saliency among objects of attention and strategies. And Christopher Hookway (2008) has argued that affective states in general embody evaluations that appeal to standards and principles of reasoning (for example, concerning inductive reasoning) that we may not be able to articulate. He claims that even if one can offer no reasons to justify one’s acceptance of some inference, they may possess an *immediate phenomenology* of being compelling, as having epistemic salience, which is an affective state rather than a cognitive one. (Cf. Elgin 2002; Thagard 2008).[[9]](#footnote-9)

Let’s begin with the well-studied feeling of knowing.[[10]](#footnote-10) This is an experience we have whenever we are asked to recall a piece of information that seems to us to indicate that we possess the information without us (as yet) being able to recall the information. Psychological studies of memory retrieval suggest that subjects can accurately determine whether they are going to be able to recall the information by means of the feeling of knowing before they even try to recall it.[[11]](#footnote-11)

As noted above, psychologists have proposed that the origin of epistemic feelings is low-level metacognition, which involves a sub-personal mechanism that monitors the performance of different cognitive processes. There is debate about how exactly to understand the nature of such a mechanism, but one plausible way is to think of it as a heuristic device that evaluates mental activity by reference to external conditions and/or properties of the relevant cognitive processing – such as fluency or familiarity – as well as by reference to some salient concepts and theories, as the conceptual nature of some E-feelings suggests.[[12]](#footnote-12)

What, then, are such feelings actually about? Arguably, it seems that epistemic feeling have a dual intentional content; on the one hand, they are in some way about our own cognitive states– such as our capacity to know or remember something – and on the other hand they are about the actual specific piece of information or object concerned. Phenomenologically, however, the main focus of our epistemic feelings will often be simply the relevant object or task at which our cognitive processes are directed, which explains why we attribute aesthetic features to it, rather than to our own mental states. This will be because, after all, the object or task is what grabs most or all of our attention. For, on the one hand, it takes some cognitive effort to attend to our own mental processes, while on the other hand, such attention will normally be seen as irrelevant to the task in hand, for example carrying out the implications of a SM.

In any case, the feeling of understanding clearly plays a central role in scientific reasoning, and particularly in the utilisation of SM. One of the crucial factors that appears to have some influence on the elicitation of this and other epistemic feelings is the fluency of the task, where fluency is, roughly, the experienced ease with which mental content is processed. (R. Reber, Schwarz, & Winkielman, 2004). As Reber et al. (2008) note, many studies have demonstrated that stimuli processed with greater ease elicit more positive affect (R. Reber, Winkielman, & Schwarz, 1998; Whittlesea, 1993; Winkielman, Halberstadt, Fazendeiro, & Catty, 2006), and that fluency plays a role in the rejection of theories that are difficult to understand (McColm, 2007). Processing fluency increases either through former exposure, such as with stimulus repetition (e.g., Jacoby & Dallas, 1981) and associative learning (e.g., Posner & Keele, 1968; A. S. Reber, 1967), which renders stimuli familiar, or through stimulus features, such as simplicity (Garner, 1974) and symmetry (Palmer, 1991; Royer, 1981), that facilitate perceptual processing.

Reber et al. (2008) set out to study the role of fluency in mathematical reasoning and its relationship to certain properties of stimuli – such as simplicity or symmetry – that have also been implicated in experiences of beauty. They examined the use of symmetry as a cue for correctness in an arithmetic verification task by manipulating the symmetry of sets of dot pattern addition equations.[[13]](#footnote-13)



They found that speeded decisions about the correctness of these equations led to higher endorsements for both correct and incorrect equations when the addend and sum dot patterns were symmetrical. That is, people without enough time to analyse the problem instead use heuristic cues – the presence of symmetry – in their assessment of the correctness of a proposed solution. Therefore, they argue, this effect does not seem to be due to the fact that symmetry facilitates calculation or estimation.[[14]](#footnote-14)

We ought, however, to proceed with some caution. Currie (2016), for example, has pointed out that in cases where people are asked about the truthfulness of a story their ‘feeling for truth’ is highly unreliable, often having more to do with, for example, the presence or rhyme, the vividness of the imagery, intensity of emotional stimuli, or the attractiveness of the speaker. Perceptual fluency – perceived ease of processing - is clearly operative here. Currie goes on to argue that, in contrast to fiction, SM are “not dependent for their value in learning on any particular formulation; rather they depend on their capacity to get good predictive or explanatory results or to achieve some other epistemic aim.” (305)

It is here that I think Currie is mistaken. First, because the formulation of SM is crucial to their epistemic import, and in particular to their explanatory value, which is in large part a function of the feeling of understanding that they can produce. It is important to note that the studies on fluency outlined above, even though they focus on mathematical judgements, are primarily concerned with perceptual processing. It is the connection between the ‘perception’ of imagery and the feeling of understanding that accompanies them, that is fundamental to the success conditions of at least some SM. Secondly, in this light, the relevant epistemic feelings at play in SM – particularly the feeling of understanding – are not valuable simply in terms of their reliability as ‘truth-trackers’. The notion of understanding is more pertinent to the cognitive function of SM than truth.

In an earlier study Reber et al. (2004) also identified processing fluency at work in purported judgements of beauty, thus promising to connect judgements of truth and judgements of beauty together via the medium of fluency and via epistemic feelings. Specifically, Reber et al. appealed to previous empirical experiments as well as their own studies to argue that “aesthetic pleasure is a function of the perceiver's processing dynamics: The more fluently perceivers can process an object, the more positive their aesthetic response.” (p. 364) They examined a number of variables taken to influence aesthetic judgments, such as figural goodness, figure-ground contrast and clarity, stimulus repetition and familiarity, symmetry, and prototypicality, and tried to trace their effects to changes in processing fluency. They also looked at the role of other variables, like visual or semantic priming, that appear to influence judgments of aesthetic pleasure. The range of studies cited and performed is too large to discuss in any length here but, in their own words, the main findings were the following:

“First, objects differ in the fluency with which they can be processed. Features that facilitate fluent processing include all the core features identified in objectivist theories of beauty, like goodness of form, symmetry, and figure- ground contrast, as well as variables that have not received attention in traditional theories of aesthetic pleasure, like perceptual and conceptual priming procedures. Second, processing fluency is itself hedonically marked and high fluency is subjectively experienced as positive, as indicated by psychophysiological findings. Third, the affective response elicited by processing fluency feeds into judgments of aesthetic appreciation, unless the informational value of the experience is called into question. Finally, the impact of fluency is moderated by expectations and attribution.” (377)

Some features of their study and related studies are important to note. First, the stimuli for many of the experiments – with the exception of priming experiments – are often simple visual figures, rather than sophisticated visual artworks, and accordingly preference is given to visual stimuli. Second, the experiments depend upon the self-reports of subjects concerning their affective responses, including judgements of pleasure and preference, but rarely of beauty, as we’ll note below. Third, the authors claim that although aesthetic preferences *always* depend on fluency, experiences of fluency can be influenced by both biological equipment and socialization. This is important in explaining the differences between, for example, novice and expert preferences and a number of other variables resulting from the experiments. This finding fits too with other research in showing that epistemic-aesthetic feelings seem to be cognitively penetrable: that is, they can be influenced by top-down processing involving certain background knowledge, assumptions and expectations. For example, complexity may sometimes be preferred to simplicity by experts because it facilitates access to the meaning of the stimulus. “That is, a decrease in perceptual fluency due to complexity may be outweighed by an increase in conceptual fluency due to meaningfulness.” (373)

One might wonder here how, if fluency processing can be the result of certain contingent features of one’s background knowledge, expectations and so on, such feelings could possibly be relied upon for epistemic insight. Such a worry, I believe, is misplaced. This is because, once we have the notion of expertise in play – scientific or artistic – we have a grasp of certain conditions that appropriately govern the first-order responses of the expert and this ensures that such responses possess a measure of objectivity. This is the case even where, as in art, the relevant expertise is itself in part the result of ‘mere’ historical conventions, but in the case of scientific expertise the role of mere convention is clearly subordinate to more or less universally accepted methodological constraints and well-established theories.[[15]](#footnote-15)

I have argued elsewhere that, in light of these findings and other considerations, we can think of (some) epistemic feelings as possessing aesthetic attributes, or of (some) aesthetic feelings as exhibiting epistemic attributes, or of a range of feelings that are jointly aesthetic-epistemic in nature (Todd 2017) First, epistemic feelings, like aesthetic experiences, are valenced. They are experienced as positive or negative. This, plausibly, is a result of them being manifestations of some sort of meta-cognitive monitoring of how well or badly, efficiently or inefficiently, our cognitive process are engaging with an object or task. Second, epistemic feelings, like aesthetic experiences, can be and perhaps often are quick and dirty responses that are opaque, at least initially, to the reasons that ground them. Third, let’s not forget, in the context of scientific practice these epistemic feelings are often characterised as aesthetic. The nature of the experiences is, to the subjects undergoing them, experienced as being of the same (rough and ready) kind as those present in paradigmatic aesthetic contexts.[[16]](#footnote-16) Finally, as we have seen, many of the criteria and stimulus properties occur as the objects and causes of both aesthetic and epistemic experiences – symmetry, simplicity, fluency, order, clarity and so on.

The two notions I want to concentrate on here are those of ‘understanding’ and ‘fit’. The ‘Aha!’ moment that encompasses a surprising discovery, or simply reflects the fact that some impressive intellectual achievement or insight has been accomplished can be the result of

a feeling of fluency, and seems often to have something to do with the notions of harmony or fit. Here we find, as many have pointed out, come striking continuities between aesthetic judgement and scientific reasoning, in terms of the appreciation of patterns, connections, symmetries and harmonies common to each.[[17]](#footnote-17) This notion of fit, as Wittgenstein long ago remarked, seems central to many aesthetic experiences, although it is very difficult to articulate precisely. Yet I think that there is a distinctive type of feeling that accompanies the ‘perception’ of fittingness and it is very closely related to, or perhaps a variant of the feeling of understanding.

Mike Stuart (2016) lists a number of ways that thought experiments in science can increase understanding, which he divides into the sub-categories of explanatory understanding, practical understanding, and objectual understanding (OU). If we look only at the latter, Stuart characterizes this in terms of Camp’s notions of perspectives, characterization, and frames. OU-oriented thought experiments, he states, can be understood as frames which are meant to lead us into certain characterizations. He says:

‘Some of Darwin’s opponents characterized the eye as a watch. Even if we saw a watch on a deserted island, we would nevertheless assume the watch was created because of its complexity and obvious purposefulness. This frame suggests a characterization of the eye as being like a watch, which is complex, purposeful and the product of intentional creation. That is how the frame casts doubt on the idea that eyes are the result of a series of chance mutations. Darwin, on the other hand, presents a competing characterization using his thought experiment, which narrates a series of mutations that could plausibly result in a fully functioning eye beginning with a single nerve. This characterization makes it easy to see the eye as having evolved…’ (535)

This kind of understanding is not fundamentally propositional or even factive, and nor is much of the understanding that results from scientific reasoning, as for example Elgin has frequently pointed out in her work. (e.g. 2002; 2007; 2014) As she suggests, the idealizations that abound in science are essential in offering an irreplaceably direct epistemic to certain features of the phenomenon we want to understand. Imagery can play a crucial role in doing so, and insofar as SM employ imagery to highlight certain properties, or to focus our attention in certain ways, the understanding that results is partly non-propositional and affective in nature. Such understanding, I contend, frequently has an aesthetic character, a feeling of fit.

One key components to the feeling of understanding present in scientific reasoning is unification. As philosophers such as De Regt, Elgin, and Stuart have pointed out, understanding a phenomenon in science – such as the kinetic theory of gas explained in Boyle’s Law – frequently requires unifying often disparate elements together, seeing how they interconnect in a way that is intelligible. Such unification is often aided by visualisation, no doubt in part because human beings are primarily visual creatures. This is why we rely on visualisation for understanding even the most abstract areas of science, and why, when phenomena outstrip our ability to visualise them – such as in the case of various puzzling quantum phenomena – it is difficult to grasp them in a way that satisfies our desire for explanation and understanding.

Importantly for our purposes, it is not just the role of visualisation as such that plays a central role in understanding, but also the connection that it has to certain affective-epistemic states. We saw earlier that various philosophers have appealed to the cognitive role affective states may play in guiding our judgements in lieu of propositional or ‘rational’ processes, and we have seen how this may be explained in part by processing fluency and the epistemic-aesthetic feelings that are manifestations of it. De Regt and Dieks talk of how understanding in science is often the result of certain intuitive ‘judgements’ we make, intuitions that often but not always arise out of visualisation and which play a crucial heuristic role. A scientific theory, they contend, should be intelligible, in that we want to be able to ‘grasp how the predictions are generated, and to develop a feeling for the consequences the theory has in concrete situations.’ (144) They note that, in the visualised case:

‘A simple illustration is the use of ‘field lines’ in electrostatics … Although intuitive application of this concept is possible only in simple situations, it is quite useful to get a feeling of how electrostatic systems behave. And this, according to Feynman et al. (1965, vol. 2, 2-1), is precisely what it means to have physical understanding of the situation in question: “if we have a way of knowing what should happen in given circumstances without actually solving the equations, then we ‘understand’ the equations, as applied to these circumstances”’[[18]](#footnote-18) (159)

de Regt does not say much about the last two constraints, but takes it to be

rather self-evident that any understanding providing explanation features them, although perhaps to

different extents (pp. 36-38, 93). His focus lies on the intelligibility criterion, which is intersubjectively

defined (p. 40):

Intelligibility: 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 theor

The role of intuition has also been noted by Cartwright (1983), who argues that applying a model to a real system is a matter of intricate approximation. Formal principles, telling us how to get from a theory via a model to a description of a real system, do not exist: “There are just rules of thumb, good sense, and, ultimately, the requirement that the equation we end up with must do the job” (ibid., 133) I suggest that ‘good sense’ here is nothing other than the kind of intuitive epistemic-aesthetic feeling of understanding or fit that I have been discussing.

To sum up briefly: several philosophers have noted that visualisation is crucial to some scientific models, and hence can play a fundamental role in scientific reasoning. Others have contended that the notion of understanding rather than truth is central to the cognitive value that of SM, and several have discussed the role of feelings, intuitions, and aesthetic judgements in science. Looking closely at experimental work on processing fluency, and on the epistemic role of certain aesthetic feelings allows us, I have argued, to understand how all of these aspects may be connected, and hence to gain a clearer overview of how scientific reasoning works.

It remains only to end with some remarks on the connection between imagistic opacity and the relevant affective states, as I promised at the very beginning. Unfortunately, however, it is rather difficult to be precise here, and I can’t pretend to offer anything other than the briefest sketch of what are, after all, certain cognitive processes that operate largely at sub-personal levels.

Opacity, recall, is that feature of images in virtue of which we are aware of the ‘phenomenological voluntariness’ of the mental state we are in: roughly, of the fact that we are imagining and are therefore normally responsible for the content of our imagery. It is partly this feature of imagining and imagery that leads directly to scepticism about the epistemic value of each in scientific reasoning. We can now begin to see, however, how imagery can be driven – and can in turn drive – certain affective reactions (aesthetic-epistemic feelings and intuitions) that constitute the feeling of understanding.

To be sure, these feelings may in certain cases arise independently of imagery, as is arguably the case in abstract mathematics. Nonetheless, where imagery seems inescapable in scientific reasoning, it is often accompanied by feelings that stem directly from the phenomenal character of imagining itself. That is, where imaginings are driven by processes that underpin the kinds of epistemic-affective feelings we experience in scientific reasoning, the feeling of understanding or fit that results is not the kind of feeling that could result from some passive perceptual or belief state. The conscious effort, intention, and attention that goes into imagining ‘seeks’ a kind of reward or satisfaction that only such aesthetic-epistemic feelings can provide – or rather, of which such feelings are the natural manifestation. Where visualisation is present, such feelings will necessarily be bound up with the kind of visual aesthetic features – of harmony, coherence, unity, symmetry and so forth – that we have discussed.

As such, what and how we visualise in SM will be driven in part by theoretical principles and considerations, and in part by propositional imaginings, but also by affective intuitions that may be below conscious awareness. In turn, our visualised scenarios may themselves arouse further affective states, and amongst such states the feeling of understanding is one of the most important in scientific reasoning.

**Bibliography**

Arango-Muñoz, S. & Volz, K. (2015), ‘Oops, scratch that! Monitoring One´s Own Errors during Mental Calculation’, *Cognition* 146: 110-120.

Arango-Muñoz, S. (2014), ‘The Nature of Epistemic Feelings’, *Philosophical Psychology* 27: 193–211

Arango-Muñoz, S. & Michaelian, K. (2014), ‘Epistemic feelings, epistemic emotions:

Review and introduction to the focus section’, *Philosophical Inquiry* II: 97-122.

Arnheim, R. (1996) ‘Beauty as Suitability’, *Journal of Aesthetics and Art Criticism* 54: 251-3.

Cartwright, N. (1983). *How the Laws of Physics Lie*. Oxford: Clarendon Press.

Chandrasekhar, S. (1987) *Truth and Beauty: Aesthetics and Motivations in Science* (University of Chicago Press: Chicago)

Currie, G. (2016). ‘Models and Fiction, Fictions as Models’, *The Monist* 99: 296-310.

De Regt, H. & Dieks, D. (2005), ‘A Contextual Approach to Scientific Understanding’, *Synthese* 144: 137-170.

De Sousa, R. (2008) ‘Epistemic Emotions’ inBrun, Doguoglu & Kuenzle (eds.) *Epistemology and Emotions* (Aldershot: Ashgate)

Dokic, J. (2012) ‘Seeds of self-knowledge: noetic feelings and metacognition’ In Beran, Brandl, Perner, & Proust, (eds)., *Foundations* *of metacognition* (Oxford: Oxford University Press), 302-321.

Elgin, C. (2002) ‘Art in the Advancement of Understanding’, *American Philosophical Quarterly* 39: 1-12.

Elgin, C. (2007), ‘Understanding and the Facts’, *Philosophical Studies* 132: 33-42.

Elgin, C. Z. (2014) “Fiction as thought experiment,” Perspectives on Science 22: 221–241.

Engler, G. (1990) ‘Aesthetics in Science and Art’, *British Journal of Aesthetics* 30: 24-33.

Frigg, R. (2010a) “Models and Fiction,” Synthese 172(2): 251 268.

Frigg, R. (2010b) ‘Fiction and Scientific Representation,” in R. Frigg and M. Hunter (eds.) *Beyond*

*Mimesis and Convention: Representation in Art and Science*, Dordrecht: Springer.

Gendler, T. (2004) ‘Thought Experiments Rethought – and Reperceived’, *Philosophy of Science* 71: 1152-63.

Glynn, I. (2010) *Elegance in Science: the beauty of simplicity* (Oxford: Oxford University Press)

Gregory, D. (2016). ‘Imagination and Mental Imagery’, *The Routledge Handbook of Philosophy of Imagination* ed. A. Kind (London: Routledge): 97-109.

Hookway, C. ‘Epistemic Immediacy, Doubt and Anxiety: on a role for affective states in epistemic evaluation’ (2008) inBrun, Doguoglu & Kuenzle (eds.) *Epistemology and Emotions* (Aldershot: Ashgate)

Kivy, P. (1991) ‘Science and Aesthetic Appreciation’, *Midwest Studies in Philosophy* 16: 180-95.

# Koriat, A. (2000) ‘The feeling of knowing: some metatheoretical implications for consciousness and control.’, *Consciousness and Cognition* 2: 149-71.

Kosso, P. (2002) ‘The Omniscienter: beauty and scientific understanding’, *International Studies in the Philosophy of Science* 16: 39-48

Lipton, P. (2004) *Inference to the Best Explanation* (London: Routledge).

McAllister, J. (1991) ‘Scientists’ Aesthetic Judgements’, *British Journal of Aesthetics* 31: 332-41.

McAllister, J. (1996) *Beauty and Revolution in Science* (New York, Cornell University Press).

McAllister, J. (2005) ‘Mathematical Beauty and the Evolution of the Standards of

Mathematical Proof’, in: M. Emmer (Ed.) *The Visual Mind II* (Massachusetts: MIT Press): 15-34.

McGinn, C (2006). *Mindsight* (Harvard: Harvard University Press)

Osborne, H. (1984) ‘Mathematical Beauty and Physical Science’, *British Journal of Aesthetics* 24: 291-300.

Reber, R., Schwarz, N., Winkielman, P. (2004) ‘Processing Fluency and Aesthetic Pleasure: Is Beauty in the Perceiver's Processing Experience?’, *Personality and Social Psychology Review* 8: 364-382

Reber, R., Brun, M., Mitterndorfer, K. (2008). ‘The Use of Heuristics in Intuitive Mathematical Judgement’, *Psychonomic Bulletin & Review* 15 (6): 1174-1178 .

Root-Bernstein, R. (2002) ‘Aesthetic Cognition’, *International Studies in the Philosophy of Science* 16: 61-77.

Salis F, and Frigg, R. (2017) ‘Capturing the Scientific Imagination’, in Peter Godfrey-Smith and Arnon Levy (eds.): The Scientific Imagination. New York: Oxford University Press.

Soteriou, M. (2010) ‘Perceiving Events’, *Philosophical Explorations* 13: 223-41.

Stuart, M. (2018) ‘How Thought Experiments Increase Understanding’, *The Routledge Companion to Thought Experiments* eds. M. Stuart, Y. Fehige, J. Brown (London: Routledge): 526-544.

Thagard, P. (2008) *Hot Thought* (MIT: Bradford Books)

Todd, C. (2008): ‘Unmasking the truth beneath the beauty: Why the supposed aesthetic judgements made in science may not be aesthetic at all’, *International Studies in the Philosophy of Science* 11: 61–79.

Todd, C. (2017). ‘Fitting Feeling and Elegant Proofs: on the psychology of aesthetic evaluation in mathematics.’ *Philosophia Mathematica*. Online.

Toon, A. (2016), ‘Imagination in Scientific Modelling’ in A. Kind (ed.) *The Routledge Handbook of the Philosophy of Imagination* (London: Routledge).

Walton, K. (1970), ‘Categories of Art’, *Philosophical Review* 79: 334-367.

Zeki, S., Romaya, P., Benincasa, d., Atiyah, M. (2014) ‘The experience of mathematical beauty and its neural correlates’, *Frontiers in Human Neuroscience* 8: 1-12.

1. See also Salis & Frigg (2017), p. 2. [↑](#footnote-ref-1)
2. Cf. Currie (2016) for a similar sceptical view about the analogy between SM and fiction, though he appeals to different considerations. [↑](#footnote-ref-2)
3. For a good overview of these issues see Gregory (2016). [↑](#footnote-ref-3)
4. For an accessible discussion of all of these features see McGinn (2006) [↑](#footnote-ref-4)
5. The Perky experiments might seem to cast doubt on this claim, but their interpretation is controversial, and I any case the phenomena they show are applicable only in very restricted settings. [↑](#footnote-ref-5)
6. What follows draws largely on my paper Todd (2017). [↑](#footnote-ref-6)
7. Note here that I am concerned primarily with the phenomenology of understanding and hence the role of feeling in SM. There are, of course, other ways of understanding the role of ‘understanding’ in scientific reasoning, some of which I will discuss below. (e.g. De Regt & Dieks 2005; Stuart 2016) [↑](#footnote-ref-7)
8. See Arango-Munoz & Michaelian (2014) and Arango-Munoz (2014) for discussion. [↑](#footnote-ref-8)
9. These lines of thought are compatible with recent philosophical accounts of the emotions as states or processes whose function is largely to disclose certain evaluative states of affairs, and which is accomplished primarily via their experiential phenomenology. See Deonna and Teroni (2012) for discussion. [↑](#footnote-ref-9)
10. The *locus classicus* is Koriat (2000). [↑](#footnote-ref-10)
11. See Reder (1987), (1988), (1996). [↑](#footnote-ref-11)
12. See Arango-Munoz (2014) One recent study has shown that certain gut feelings, such as the feeling of error, can be reliable indicators of the accuracy of one’s own mental performances in mathematical reasoning tasks. Arango-Munoz et al. (2015) showed, for example, that the feeling of error was strongly correlated with arithmetic errors in a Number Bisection Task, where the instructions and time restriction imposed ensured that the answers to the questions were the first that quickly and intuitively came to participants’ awareness. This suggests, in the words of the authors, that “this type of feeling-based metacognition provided participants with accurate assessments of their ongoing cognitive processes without the necessity of effortful and analytical thinking”. (31) [↑](#footnote-ref-12)
13. Participants were presented with dot pattern addition equations, one by one. Half were correct (e.g., 15 􀀑 18 􀀕 33), and half were wrong (e.g., 15 􀀑 18 􀀕 27). The incorrect sums were either smaller or greater than the corresponding correct result, and the difference between the two was balanced across symmetry conditions. Each equation was shown twice, once as a symmetric pattern, once as an asymmetric pattern, yielding 96 dot-pattern-shaped equations (Figure 1). All symmetric patterns were rectangles, with from three to five rows. Operands with asymmetric patterns always had as many dots and as many rows as the same operand with symmetric patterns, but the dots were rearranged so that they possessed neither vertical nor horizontal symmetry. [↑](#footnote-ref-13)
14. Semir Zeki et al. (2014) have directly tackled mathematical experiences of beauty, focussing on a list of mathematical formulae. Zeki et al found some agreement about the aesthetic judgements of certain formulae. They found, for example, that the formulas most consistently rated as beautiful were both before and during the fMRI scans were Euler’s identity (1 + eiπ = 0) and that the one most consistently rated as ugly was Ramanujan’s infinite series for 1/π. The experimenters were focussing on the hypothesis that such experiences correlate with activity in the same part of the ‘emotional brain’ – specifically A1 of the Orbito Medial Frontal Cortex (oMFC) – as experiences of beauty towards other paradigmatic aesthetic stimuli, such as visual artworks and music. The results in favour of a positive conclusion come with the observation that this area is also active in a variety of (arguably non-aesthetic) conditions, including experiences relating to pleasure, reward and hedonic states. Although this might be interpreted as showing that similar brain areas are operative in aesthetic experiences and experiences of understanding, I think we need to be extremely cautious in investigating what sort of overlap is implied. For example, as a certain level of understanding is required to have the aesthetic experiences in the first place, but I want to argue that the feeling of understanding can itself be an aesthetic feeling. [↑](#footnote-ref-14)
15. For further discussion see Walton (1970) and De Regt & Dieks (2005). [↑](#footnote-ref-15)
16. For example, in response to Ramanujan’s work on identities, Watson said that it gave him “a thrill which is indistinguishable from the thrill which I feel when I enter the Sagrestia Nuova of Cappella Medicee and see before me the austere beauty of “Day”, “Night”, “Evening” and “Dawn” which Michelangelo has set over the tombs of Giuliano d’ Medici and Lorenzo d’ Medicii”. (Quoted in Chandrasekhar 1987: 61). [↑](#footnote-ref-16)
17. Cf. Root-Bernstein (2002); Lipton (2004): ch. 9; Arnheim (1996). [↑](#footnote-ref-17)
18. In the non-visualised case: ‘many theoretical physicists have developed a familiarity with, and intuition for, the general behaviour of the solutions of the mathematical equations they use. This enables them to acquire a feeling for the qualitative behaviour of the described systems without invoking picturable physical mechanisms. For instance, it is possible to get an intuitive feeling for how quantum-mechanical systems in two-slit-like situations behave, by familiarity with the linear character of the Schrödinger equation.’ (160) [↑](#footnote-ref-18)