Visual Representations in Science

Concept and Epistemology

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Chapter 4
The epistemic status of scientific visualisations

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4 The epistemic status of scientific visualisations

As the considerations in the previous chapter made clear, visual representations are, without doubt, part of many epistemic processes in contemporary science. Scientists present diagrams in their publications and talks to communicate their research results. They investigate computer-generated images as substitutes for research objects. Drawings in textbooks are used to educate novices, to introduce them to a new field of knowledge and so on. Moreover, it was pointed out that in quite a few instances images might also be used for non-epistemic purposes, for example to gain the attention of a particular audience.

The preceding contextual analysis helped to clarify and, to some degree, to systematise these diverse functional roles played by visualisations in science. However, although the functions of visual representations in epistemic contexts have been rendered identifiable, it might be argued that this is only a *descriptive* result. That is, merely noting and assessing scientific activities does not imply that these processes are also the best way to achieve the epistemic aims aspired to. Perhaps scientists are wrong in their decision to rely on visual representations to such a degree in their epistemic processes. Perhaps they should make use of other modes of representations in those instances instead.

These considerations correspond to the two perspectives inherent to the philosophy of science. Thomas S. Kuhn advises paying close attention to what is really going on in the sciences, how practices and theoretical assumptions have developed over time, and in what sense social processes have played a role in epistemic contexts. This is the *descriptive task of the philosophy of science*, the component that is supposed to connect philosophers' hypotheses and theories to real world activities in science. Considering ideal situations might be interesting and sometimes helpful, but clinging to an unrealisable ideal can also turn out to be destructive in the long run – for example, by wrongly eliminating established working practices. Yet Kuhn's advice does not mean that philosophers of science have to confine themselves to a mere unreflected recording of activities. On the contrary, there is also a second, *normative part* of their work. That is, not only are philosophers supposed to record, but also to analyse and evaluate epistemic practices observed in the scientists' strivings for knowledge. These analyses might result in regarding the prevalent practices as being defective and requiring improvements in some way. Thus, philosophers are also asked to make suggestions on how to improve those practices from an epistemological point of view.[1] Hans Poser, for instance, discusses these two aspects of the philosophy of science (see Poser 2001). He points out that, among the different disciplines that are concerned with science on a meta-level – such as the history of science, the sociology of science, etc. – the philosophy of science is unique in that it deals with descriptive as well as with normative questions about its subject (see ibid., 15ff., 36).

At least, parts of our analysis of the epistemic functions of scientific images are in this sense a descriptive endeavour.[2] Now I also want to add a normative dimension. I will investigate the question of whether scientists are right to use visualisations in the way they do. Leaving non-epistemic purposes of image practices aside, issues such as the following will have to be discussed: can people gain knowledge from visual representations? If so, what kind of knowledge do they acquire by those means? How does the process of information transmission work with respect to visualisations? Are there crucial differences in information transmission via numerical or verbal representations?[3] Is there a kind of hierarchy involved when comparing these three modes of representation from an epistemological point of view? Such a comparative task highlights what is at stake here, namely the precise *epistemic status* that visual representations possess in comparison to other representational means in epistemically relevant contexts. It has to be added that, as the functional roles of visual representations are diverse in science, it seems rational to assume that there is not one exclusive status to be ascribed to these representational means, but various ones.

In this chapter, I will focus on the explanatory context of science, the context of information transmission and the role of visual representations therein. More precisely, I am interested in the two following questions: are visual representations a suitable means in this epistemic context at all, and are there epistemic purposes that visual representations are particularly suitable to serve in comparison with competing modes of representation?

To find answers to these questions, I shall proceed as follows: firstly, an examination is needed concerning the basic philosophical problem that underlies the discussion of the epistemic status of scientific images. The question is why philosophers are concerned about visual representations in epistemic processes at all? What do they think is wrong with scientific practices making use of images? Is there anything wrong at all? At this point, there will be a return to Perini's considerations, mentioned at the beginning of this book. The apparent tension, pointed out by her, that appears when comparing actual scientific practices and philosophical reflections about them (see Perini 2005c, 913f.) will be discussed, as well as the nature of arguments, and it will also be explained why philosophers think that visual representations are not suitable means to be used in argumentation. This critical attitude will be contrasted nonetheless with some suggestions on how to conceive *visual arguments*.

These considerations will direct an investigation into the *cognitive content* of visual representations, which will form the second part of the analysis. On the one hand, that information presented in different representational modes can, at least partly, be translated from one mode to another speaks in favour of the thesis that visual representations can contain a cognitively accessible content. On the other, as already mentioned, some philosophers and semioticians (see e.g. Eco 1994, ch. 7) object that communicative acts based on visual representations face serious limitations of expression. I will contrast these rather critical stances towards the epistemic capabilities of visual representations with the more optimistic assessments put forward by Kulvicki as well as by Kitcher and Varzi (see Kulvicki 2010a; Kitcher and Varzi 2000). This discussion will lead to the task of more seriously considering the way cognitive access is obtained to the content of visualisations, namely via perception. It has to be asked *what kind of knowledge* we acquire by making use of this epistemic source. What follows from the fact that we access pictorial information by *vision as the primary sense* of human beings to cognitively access the world?

I will argue, and this is the final part of this investigation into the epistemic status of visual representations in science, that acknowledging the fact that the information process is based on perception in this way makes clear in what sense scientific images can actually be worth, in Kitcher and Varzi's words, "2aleph0" words (see Kitcher and Varzi 2000). Apparently there are at least two different approaches to spelling out these epistemic merits of visual representations. One will lead to a discussion of different *kinds of knowledge* and the question in what sense visual representations might be particularly helpful in their transmission. The other will be about *scientific understanding* and how visualisations can contribute to its achievement.

The discussion will include a comparison of the three different representational modes, namely the visual, the linguistic and the numerical. Whereas the second part strives for the rather moderate aim of showing that these different kinds of representation reveal comparable characteristics in the context of information transmission, the last part of the analysis is more ambitious. Here, the question will be pursued whether there is a kind of epistemic surplus of scientific images not realisable with the other vehicles of communication under consideration.

4.1 Visual arguments?

As seen in the previous chapter, visual representations in the exploratory context might seem problematic for several reasons. Image manipulation, the artificial character of visualisations engendering a constructivist interpretation of their referents and the problem of theory-ladenness of observation have already been discussed. All of these difficulties dwell on the *evidential status* of visual representations in research processes. Thus, the question was whether scientists can be epistemically justified when referring to an image of their object of research to justify knowledge claims about it. The analysis above made clear that no general worry about (digitally) manipulated images, a missing referential relation between visual representation and its object of depiction, or a theoretically induced misinterpretation of visual data can be maintained that would turn visualisations in science into a particularly unreliable source of information. On the contrary, a variety of reasons were identified showing that the scientific epistemic practices are reasonable, albeit fallible.

But even though this result speaks in favour of the epistemic capacities of images in science, philosophical problems remain. Interestingly, these are expressed in particular with respect to the explanatory context, where visual representations are intentionally used to convey information. Although this potential of transmitting information motivates scientists to use images in the exploratory context too, philosophers tend to question this capacity of visual representation. In particular, they are sceptical of the ability of images to fulfil this epistemic task in argumentative contexts.

Before going into the details about the exact nature of the philosophic contention here, let me briefly draw attention to an imbalance of the philosophical discussion. The point is that, although the mode of epistemic access, namely *perception*, to information encoded in visual representations remains the same in the explanatory and the exploratory contexts, its philosophical evaluation varies. Few, if any, philosophers would deny that perception can serve as an *epistemic source*. They do not contest the claim that accessing the information encoded in visual representations will perceptually allow the recipient to acquire at least some knowledge about what was supposed to have been transmitted by their means. However, the argumentative context referring to this way of accessing information does not apparently suffice to make knowledge claims plausible which are based on this source of information. Thus, whereas perception seems to be an admissible source when it comes to scientific observations and experiments, the reasonableness of referring to it in the context of scientific arguments is questioned.

Now, it might be argued that what is at issue is that in many instances there is *a necessity to interpret* scientific visualisations to understand their content correctly. However, two points can be mentioned as a rejoinder.

Firstly, interpretations of what has been perceived also seem to play a role with regard to ordinary instances of perceiving the world. The more precise the observer's background knowledge is, the more she will be able to discern, as Alan F. Chalmers makes clear when comparing a layman's observations with those of a professional botanist travelling through the Australian bush (see Chalmers 1999, 11f.). He points out that, undoubtedly, the botanist will perceive more and also more detailed facts about the native flora than the layman will be able to notice. What explains this is that the botanist "has a more elaborate conceptual scheme to exploit" (ibid.) than the layperson. That is, the botanist has more background knowledge at her disposal than the layperson with which to reason about what exactly she has observed. Thus, the necessity of interpretation in the process of understanding is by no means a unique feature of visual representations.

Secondly, background knowledge about the reliability of the instrument and about the mapping function that defines the informativeness of the resulting image with respect to the object depicted limits the spectrum of possible interpretations of scientific visualisations reasonably. Scientists' reasoning is not driven by guesswork, but by these theoretical and practical restrictions. Hence, highlighting the relevance of interpretations to understand scientific images does not constitute a rationale framed to question their assumed epistemic capabilities.

Actually, the bone of contention consists in something else. It is the question about the *propositionality* of the information transmitted that is critically discussed by philosophers, especially in the explanatory context. Epistemologists still tend to understand 'knowledge' primarily as 'knowing-that', namely propositional knowledge (see Grundmann 2008, 71).[4] From this point of view, the question about the epistemic status of visual representations is essentially about their capacity to transmit propositional knowledge.

In the following, philosophical worries concerning the epistemic status of visualisations in the explanatory context will be scrutinised more closely. Moreover, an alternative approach to the topic resulting from the previous considerations about how best to analyse visual representations in the explanatory context will be discussed. All of these reflections will finally contribute to a better understanding of what kind of epistemic contributions visualisations can make with respect to scientific arguments.

4.1.1 The philosophical challenge

In the previous chapter, it has been argued that scientific images possess the *capacity of information recording, storage and transmission*. Contrary to scientists making use of these capacities in their epistemic processes, philosophers still call them into question in the explanatory context. What exactly are the difficulties that cause this sceptical attitude in philosophy?

Apparently not all branches of philosophy are affected alike by these misgivings. Yet, as pointed out above, epistemologists and philosophers of science have shown crucial shortcomings in dealing with visual representations until rather recently. Two aspects are relevant to explain these difficulties in dealing with visual representations. On the one hand, there is a certain philosophical tradition which can be traced back to Plato and René Descartes, whose proponents question the suitability of images as epistemic means. On the other hand, a particular focus on (natural and formal) language in analytic philosophy and, consequently, in the philosophy of science being based on this tradition, has to be mentioned in this context.

The first aspect has often been pointed out as a difficulty in picture theory. I will therefore only briefly summarise the related line of reasoning.[5] Perception is commonly regarded as a source of knowledge nowadays, but this has not always been the case. In particular, so-called *rationalists* were rather sceptical about the reliability of sense perception as an epistemic source. It is here that Plato's and Descartes's misgivings can be subsumed. Both are convinced that observation is not able to yield knowledge and that we have to rely on reason instead if we are looking for a secure basis for our knowledge claims. Consequently, if perception is not admissible as a source of knowledge, perceiving images cannot fare much better from an epistemological point of view. Plato explicitly discusses the case of images in his *Politeia*. Here he points out that pictures only mimic the entities of the real world, which themselves are only imitations of ideas. Consequently, images only show the appearances of appearances, but not the essence of things. This is why they are not suitable means to transmit knowledge (see Platon 2006, Politeia 597a-598d).

Descartes is similarly sceptical about our perceptual abilities to acquire knowledge of the world. He discusses the unreliability of sense perception in his attempt to point out a secure foundation for our knowledge system (see Descartes 1994). He makes his worries particularly clear when analysing, as an example, what the essence of 'wax' might be (see ibid., 23f., Second Meditation). Here he demonstrates that we cannot rely on our perceptual abilities to answer this question, as apparently none of the characteristics that can be observed, tasted or felt remain unaltered if the wax is heated. Descartes infers from this that none of these properties belong to its essence. To put it differently, perception is not a reliable source of knowledge if we are interested in investigating those essential facts. Yet, if perception in general cannot be regarded as a reliable epistemic source, picture perception cannot be taken as an epistemic means either. Obviously, philosophers following this rationalist tradition will then be rather reluctant to take visual representations into account in their epistemological analyses.

Jakob Steinbrenner addresses the second point mentioned above. He highlights the fact that most of all the *focus on language* of early analytic philosophers still influences philosophic discourse. He describes the resulting difficulties via a comparison of some of Gottlob Frege's main theses about verbal expression with characteristics of images (see Steinbrenner 2009, 285f.). What becomes clear is that none of the main features of verbal expressions – for example, being truth-bearers or being objects of logical operations such as expressing inferences, entailments, negations – show (at first glance) an analogous counterpart in visual representations. Steinbrenner adds that, even though none of these theses has remained uncontested by contemporary analytic picture theorists,[6] this heritage of the philosophical founding fathers, so to speak, has long hindered a thorough tackling of the topic in analytic philosophy (see ibid., 286). Yet what exactly did Frege say that caused these problems?

In *The Thought. A Logical Inquiry* (Frege 1956),[7] Frege deals with the topic of truth. In particular, he is interested in the question concerning what entities can be bearers of truth values. He suggests that it is only "thoughts" that can fulfil this task. But what exactly is it that he calls a "thought"? Frege offers the following description:

> [w]ithout wishing to give a definition, I call a thought something for which the question of truth arises. [...] the thought is the sense of the sentence without wishing to say as well that the sense of every sentence is a thought. The thought, in itself immaterial, clothes itself in the material garment of a sentence and thereby becomes comprehensible to us. We say a sentence expresses a thought.
>
> (Frege 1956, 292)

From his point of view, a thought is then an *abstract object*.

It is already inherent to this short summary of Frege's theses on thoughts what constitutes the basis for our problems with respect to scientific images. The two relevant phrases are 'bearers of truth values' and 'sense of a sentence'. Why are these two characteristics of thoughts so problematic in the current context?

Firstly, with regard to truth, Frege explicitly states that it is truth at which scientists aim. "What are called the humanities are more closely connected with poetry and are therefore less scientific than the exact sciences which are drier the more exact they are, *for exact science is directed toward truth and only the truth*" (ibid., 295, my italics). Consequently, if we are interested in scientific endeavour characterised in this way,[8] we have to focus our attention on those entities that can contribute to this attempt. This introduces the second point of concern derived from Frege's account.

The question is, what kinds of entities are possible candidates for our analysis and, in particular, whether visual representations are amongst them. There are two lines of reasoning related to this question in Frege's text. One is explicitly about images, the other about bearers of truth values. Frege questions whether our common habit of calling pictures true is justified (see ibid., 290ff.). He points out several aspects in this regard. In particular he makes clear that it is not a material object that we call true, but a representational relation intentionally brought about (see ibid., 290). This is why we use the adjective 'true' regarding pictures but not regarding other material objects such as stones. To be concise, Frege suggests that our practice of calling pictures true is a comprehensible, albeit illegitimate, extension of the scope of the term 'true'. He states that "what is *improperly* called the truth of pictures [...] is reduced to the truth of sentences" (ibid., 291f., my italics). It is not pictures that can be called true, but sentences – or, more precisely, the sense of sentences, as Frege claims.

Gombrich reiterates this point in picture theory, when he states that in the same sense that verbal assertions cannot be called red or green, pictures cannot be called true or false (see Gombrich 2004, 59).[9] It seems as if visual representations belong to the wrong category and thus cannot be considered seriously when epistemologically reflecting on the pursuit of truth in science.

From Frege's point of view, they cannot be the bearers of truth values, and thus cannot contribute to the proclaimed epistemic aim of science.

However, this critical stance towards visual representations in epistemic contexts derived from Frege's account did not remain uncontested. As there will be a discussion in detail concerning the possibility of visual arguments, and thus the connected question about the truth-bearing capacities of scientific images, in the following two sections, I will only briefly mention, as a concluding remark, two philosophers who argue for a positive status of scientific images.

Firstly, there is Marcia Eaton, who explicitly tackles the question about truth values of visual representations (see Eaton 1980). Similar to my approach, she suggests regarding images as parts of communicative acts. She also makes use of Kjørup's suggestions (see ibid., 16), mentioned in our analysis above. It is by this embedding of visual representations in communication that they can be regarded as (parts of) assertions. Now, Eaton argues that it is these assertoric acts that are evaluated along the lines of truth and falsehood. In detail, her approach amounts to the following thesis:

> [t]hus pictures lie somewhere between interpreting a set of symbols and interpreting a state of affairs. Judging that a picture is true or false necessitates the viewer's taking an active role in which he or she first formulates a statement which he or she believes to be a possible interpretation of the picture and then relates that statement to his or her beliefs.
> (Eaton 1980, 21)

Here, Eaton states her conviction that the content of images has to be translated into linguistic expressions before the question of truth can be tackled. In this sense, she tries to evade the difficulties pointed out above in a twofold sense, namely (a) by claiming that images can be translated into sentences and (b) that this translation, being based on the embedding of images in communicative acts, has the recipient judge what she believes the producer of the image intended to express with its aid.

Eaton's strategy seems to fit nicely with the characteristics of the explanatory context of science. Here, recipients indeed try to figure out what the intended message of a communicative act might have been. Yet, as we will see in section 4.1.3, this is only part of the meaning that can and will be extracted. Moreover, Eaton's approach is somehow at odds with what happens in the exploratory context of science. Investigating the photograph of Olympus Mons (see Figure 2.12), the scientist will not be interested in the intention of the photographer, but what this image can tell her about the height profile of this volcano on Mars.

The second scholar to mention is David C. Gooding (see Gooding 2010). He is not so much concerned with questions about truth as with processes of visual reasoning in science. Nonetheless, he points out that hypotheses based on visual representations can be empirically validated by "checking for correspondence between features derived from models and observed features" (ibid., 28). Assuming that a correspondence theory of truth rules here does not seem far-fetched. Without addressing this issue in any critical way, Gooding spells out how scientists make use of visualisations to derive hypotheses needed for explanations and predictions in their domain of research. In particular, he points out that scientists constantly manipulate their representational means. That is, he argues that it is not a particular image that is relevant to the scientist's reasoning, but a process involving different images (see ibid., fig. 10 on p. 27).

What Gooding explains here suggests an analogy to Vertesi's descriptions of how scientists work with rover images taken on Mars (see Vertesi 2015). She points out how working with those photographs, namely by digitally manipulating them, for example highlighting structures by colouring them or adding numerical or verbal explanations, converts them into maps of Mars (see, for instance, ibid. fig. 4.1. on p. 109), thereby transforming those images into tools not only to manoeuvre the rover geographically on the surface of Mars, but also in accordance with the tasks it is supposed to perform, for example, to analyse certain samples of soil (see ibid., 116ff.). Gooding describes a similar process at a more abstract level. He claims that:

> [m]oving from interpreted sources to structural models and on to process models generates visual theories that satisfy the explanatory aims of science. This transformation from simpler to more complex representations increases information content, enabling models to incorporate more domain knowledge.
>
> (Gooding 2010, 25)

Obviously, then, what allows scientists to draw inferences on the basis of visual representations is their embedding into larger processes also containing other kinds of representation.

In a similar way that Kjørup's suggestion draws attention to the wider context of image usage, Gooding's account reasonably broadens the focus of attention by calling to mind that scientific investigations and problem solving is a constant process rather than a single judgement. Helpful as this insight might be, there are nonetheless two critical remarks to be made about his proposal. On the one hand, his approach still leaves us with the question of how exactly, contrary to Frege's suggestion, images can be said to transmit information and thus constitute the basis of those processes of reasoning described by Gooding. On the other, his talk about 'models' in this context brings in another confusing issue, because it suggests the question of whether images can and should be understood as models, whereby the term 'model' itself is highly contested in the philosophy of science (see e.g. Bailer-Jones 2009; Hesse 1970; Morgan and Morrison 1999).

From this point of view, it seems advisable to set our focus back on scientific images and questions concerning their epistemic capacities. This is then the point at which to elaborate on Laura Perini's work on the topic. Contrary to Eaton, she defends the thesis that no prior translation of images into linguistic expressions is necessary to judge them along the lines of truth and falsehood.

4.1.2 Laura Perini on visual representations in scientific arguments

Not least because of Laura Perini's important contributions to the debate (see Perini 2005a; 2005b; 2005c; 2010; 2012a; 2012b; 2012c), philosophers of science have finally started discussing what the ubiquity of visual representations in science means in epistemological terms. Acknowledging this inspiring role that Perini's work has played for the philosophical discussion – and likewise for this book – her suggestions concerning the roles and status of visualisations in epistemic processes of science will be examined more closely now.

With respect to visual representations in the explanatory context, she states that philosophers tend to regard them as "'mere illustrations' that are redundant expressions of information presented in the text, or convey information inessential to the argument" (Perini 2005c, 913). Yet it seems quite unlikely that scientists would put such an emphasis on visual representations if they were that useless in the epistemic context of argumentation.

Perini not only makes us aware of this tension in the assessment of image-practices by scientists and by philosophers, she also tries to offer a different evaluation of the epistemic capacities of scientific images. Here, Marianne Ina Richter, who critically discusses Perini's attempts in her PhD thesis,[10] makes clear that there are apparently three different strategies that Perini could have chosen to make her point. She could have defended the view (i) that images *are* arguments, or (ii) that they are *functional parts* of arguments, or (iii) that visual representations *contribute* to arguments without being parts of them (see Richter 2014, 159). I agree with Richter that Perini selects the second option (see ibid., 165ff.). Yet it has to be added that Perini presents two different lines of reasoning in this respect. Firstly, she tries to show that images can indeed be proper parts of scientific arguments. Secondly, she also analyses whether there are particular epistemic tasks that can be fulfilled exclusively by visual representations.

Perini's first line of reasoning is deeply intertwined with the question about the *truth-bearing capacity* of images. She states the difficulty concisely: "[p]hilosophers define arguments in terms of sets of statements. This may explain why philosophers of science have paid so little attention to figures" (Perini 2005b, 262f.). Apparently images simply belong to the wrong representational category to play the role of premises or conclusions or, at least, proper parts of such.[11] Moreover, Perini explains why the difference between visual and linguistic representations is commonly regarded as so important in the context of argumentation.

> The support that premises provide a conclusion is analyzed in terms of validity or strength, and soundness, so any representation that is an integral part of an argument must be one to which those features could be relevant. Validity, strength, and soundness are understood in terms of the truth conditions of premises and conclusions, so representations that contribute to arguments must have the *capacity to bear truth*. To show that figures are nontrivial parts of scientific arguments, the first question that must be addressed is whether visual representations can be true or false.
>
> (Perini 2005b, 263, my italics)

Assessing arguments in a logical way presupposes that we are able to say something about (a) whether what is expressed in their premises and the conclusion is true or false, and (b) whether what is derived in the conclusion is already entailed in the argument's premises. However, these are exactly the logical characteristics that, following Frege, visual representations apparently do not possess.

Now, Perini is convinced that this last commonly held assumption is false. She tries to show that visualisations actually *can* be truth-bearers (see Perini 2005b; 2012c) and thus can be regarded as (proper parts of) premises or conclusions of scientific arguments. Her line of reasoning works as follows.

Firstly, she discusses some examples from logic and mathematics, in particular from set-theory and geometry (see Perini 2005b, sect. 1). She points out that, in this realm, there are *some* visual representations that can indeed bear truth values. She refers to Venn, Euler and Peirce diagrams and states that they allow "truth-preserving inferences from diagram to diagram" (ibid., 264).[12] To illustrate this point, take the classical example of the syllogism which entails a universal statement as one of its premises. As has been pointed out in section 2.1.4 of this book, such a universal statement can be expressed by Venn diagrams. Figure 4.1 shows how the universal statement 'All men are mortal beings' can be expressed by using a diagram instead of a sentence and, thus, how a diagram can work as a premise of the syllogism.

Furthermore, Perini points to the existence of visual proofs of certain mathematical questions, in particular in Euclidian geometry (see ibid., 265f.).[13] In what sense images can play a role in mathematical explanations is shown by Max J. Kobert, who demonstrates how visual representations can be used to explain algebraic statements (see Kobert 2010, 135f.). For instance, the formula $(a+b)^2 = a^2 + 2ab + b^2$ can be explained by considering Figure 4.2. That is, the algebraic formula is explained by turning it into a geometrical problem which can be solved visually.

Yet despite these initially positive results, Perini sets them aside by claiming that "[b]ecause scientific arguments are significantly different from the deductive diagrammatic systems […], we cannot extrapolate from their results to the figures that appear in contemporary research journals" (Perini 2005b, 267).

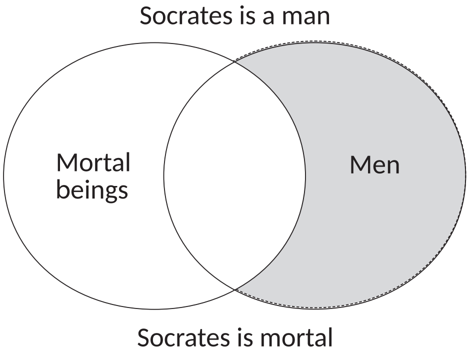

Figure 4.1 Syllogism containing Venn diagram, general statement (All men are mortal beings) expressed by Venn diagram.

Source: own image.

From my point of view, she dismisses too much here because, although Perini is right in claiming that *not all* scientific visualisations are of the kinds used in logics and mathematics, *some* are.

With respect to images used in the arguments of the empirical sciences, some points have to be made clear in advance. (1) Perini thinks of depiction along the lines of Goodman's theory as explained in section 2.2.2 of this book. That is, images are parts of symbol systems whose difference to linguistic symbol systems is characterised on the syntactic level (see ibid., 267ff.). (2) She rejects resemblance relations as the relevant feature to discern what is meant by 'depiction' (see ibid., 268). (3) Yet she admits that similarity might still play a role. She points out that, although it is by conventions that the characters of a given symbol system are ascribed their meaning, it can be the case that some conventions refer to resemblance relations to determine the meaning. "Content can also be determined by conventions that relate symbol and reference through resemblance relations" (ibid., 268).

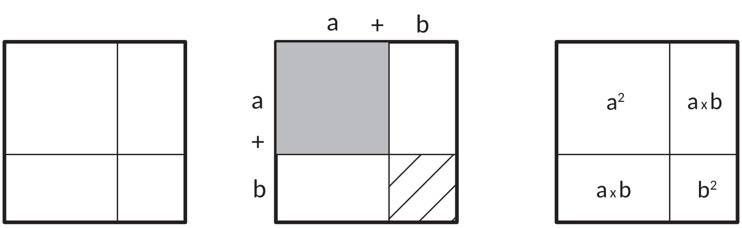

Figure 4.2 Pictorial explanation of algebraic formula ($(a+b)^2 = a^2 + 2ab + b^2$).

Source: own image.

(4) These conventions belong to particular symbol systems. That is, if an individual image is interpreted as depicting y because it resembles y, we do so because this image belongs to a particular symbol system that entails resemblance relations as interpretative rules. (5) It is not by translating images into sentences that they are assigned a meaning. (6) It is not the meaningful content of a sentence that is assessed as being true or false when images are considered (see ibid., 274). (7) It is a feature of the respective system, not of individual representations, that truth values can be ascribed to the latter (see ibid.).

Taking these points as the background to her considerations, Perini then makes use of Alfred Tarski's theory of truth to defend her claim that images can bear truth values. Now, the classical Tarskian schema of truth is: "x is true in L iff p". The standard example is: " 'snow is white' is true iff snow is white". Thus, with respect to visual representations, we now have to make clear, what 'x', 'L' and 'p' refer to. It is here that, despite her initial dismissal of linguistic expressions as mediating representations, Perini claims that we are in need of names and sentences to make statements about

> the definition of truth for a visual system.
>
> (Perini 2005b, 276)

She points out that such a definition "requires a way to assign a linguistic name to each symbol, based on its structural form, and also a linguistic expression of the content of each representation. A definition of truth for a visual symbol system consists of a statement of this form for every figure f in a system: Name(f) is true IFF statement(f)" (ibid., 276). Thus, to make claims about the truth-bearing relation between 'x' and 'p', that is, between a symbol (for example an image) and its meaning, both have to be expressed linguistically. Moreover, it is by the interpretive rules of the system to which the symbol belongs that the meaning of the respective symbol is fixed. Thus, Figure 4.1 is true, if and only if, all human beings (premise 1) are mortal (premise 2). The conventional rule that helps us to interpret this diagram consists in the following statement: *interpret the sets of two intersecting circles (1, 2) as identical if all elements of 2 belonging to the set of 1, that is, are entailed in the intersecting part of 1 and 2, and no element of 2 is left outside this intersecting part so that the remaining part of 2 is shaded, thus marking an empty set.* Interpretative rules could also be defined at an even more basic level here when the shaded part is stated to mean an empty set or the intersecting part of both circles a shared set.

Interpretative rules such as those last statements then connect an image or a symbol (x), named e.g. by calling it 'Figure 4.1' or 'intersecting part', with its meaning (p) within a particular symbol system (L). 'Meaning' is thereby understood as the reference of the symbol which can be an object, but also a state of affairs as in the example above. Interpretative rules then determine the truth conditions of a particular diagrammatic symbol. It is in this sense that Perini thinks that Tarski's theory is a suitable means by which to discuss the truth values of images.

> Tarski's work shows that even though there is no general theory of truth with which we can test individual visual representations for the capacity to have truth value […], certain symbol systems are characterized by a systematic relation between symbol form and referent, in which the truth-conditions of symbols are a function of their form.
>
> (Perini 2005b, 275)

Admittedly, such an account works very well with respect to highly conventionalised symbol systems such as the diagrammatic. However, as Perini points out herself, many images in science are not of this kind (see ibid., 279). As an example, she discusses electron micrographs (see ibid.). Despite the difficulties that she highlights with respect to images of this kind, she is optimistic that it is still possible to define a concept of truth also holding in pictorial symbol systems.

What x (symbol), p (meaning) and their relating rule are in this context has to be re-analysed in order to discover the cause of the problems here. The mapping of symbol and meaning becomes much more difficult if images are considered such as the micrograph, that is, images of a less conventional style in comparison to diagrams. In particular, there are many characteristics that are not related to any linguistic expression. Consequently, truth conditions mapping symbols to states of affairs cannot be formulated in the way suggested with regard to the diagrams above.

Therefore, Perini suggests that it is relevant to consider "the form of the image as a whole" (ibid., 280). That is, the micrograph represents the scanned sample as being of a particular shape – this is what Perini calls the "form of the image" and which constitutes the x of the Tarskian schema. The meaning (p) is the actual shape of the sample. The truth condition of an electron micrograph reads as follows, "an electron micrograph is true IFF the shape of the micrograph is a geometric projection of the shape of the sample scanned in producing the micrograph" (ibid., 280).

Yet despite this explanation of how to deal with images of this latter kind, one might object that her strategy presupposes the *translatability* of pictorial symbols into linguistic expressions to check for the relevant relation. In particular, this problem comes to mind when she contemplates the difficulties of naming entities (see ibid., 282). Many visual representations in science display characteristics, such as those depicted by the micrograph, that cannot be translated into linguistic expressions because the latter are simply not available. There are no names, not even linguistic descriptions, at the scientists' disposal either to name the symbol or to describe its meaning. If the content of such visual representations cannot then be translated and thus stated by making use of linguistic expressions, does this imply that the method employed to define truth conditions explained above is not applicable here?

Perini is aware of this objection. She claims that there are two reasons speaking against this negative assumption:

> [f]irst of all, this investigation was launched to show whether non-linguistic representations can bear truth or not. This question is begged by invoking the assumption that only representations whose content can be expressed with a linguistic form of representation have the capacity to bear truth. So, the question of whether a micrograph could be true or false cannot be settled in this way. Second, that stance does not fit with the fundamental intuition that truth value depends on reference to states of affairs, since micrographs not only represent states of affairs, but do so without their content being assigned to them through the mediation of another symbol system.
>
> (Perini 2005b, 282f.)

The first rejoinder seems to me to be a rather weak one. One can state vice versa that the necessity of translation indeed shows that pictorial representations cannot bear truth values. The consequence then would be that the project of defining a concept of truth valid for pictorial symbol systems has failed.

Perini's second rejoinder, however, is more substantial. Pointing out that truth values are connected to states of affairs and that micrographs represent such states of affairs apparently suggests itself as a criterion of evaluation. How does the representation of states of affairs work, then, in the pictorial realm? She argues that images represent states of affairs because what is represented by them is related to the latter by conventional rules that guide the interpretation of those images. This also explains why she thinks that images can represent not only visible features of their object of reference, but also invisible ones. She states that:

> [v]isual representations are defined by the fact that spatial features of the symbol are *interpreted* to refer to features of the referent – they are not defined in terms of similarity with their referents. For this reason, visual representation is not restricted to visible subject matter.
>
> (Perini 2010, 137)

William Goodwin takes a different track in criticising Perini's account of the truth-bearing capacity of visual representations (see Goodwin 2009). He is also sceptical about the theory of depiction and the theory of truth chosen by Perini. However, his main critique is focused on "the idea that the only way to understand visual representations as having a 'genuine' role in scientific discourse is by finding some way to understand these representations as capable of being true or false" (ibid., 374). Goodwin shares Perini's conviction that visualisations can play essential epistemic roles in scientific discourse. However, contrary to her approach, he thinks that this important task can be explained without struggling with their presumed capacity to bear truth values. How then does Goodwin conceive of the precise epistemic function of visual representations in scientific arguments?

The starting point of his objection is his asking what the expression 'contributes to an argument' might mean. From Perini's point of view, making such contributions implies that the respective entity plays the role of (parts of) premises or conclusions. As Goodwin claims, such a conception means that "a representation 'contributes to an argument' only by being in logical or evidential relationships with the other representations in the argument" (ibid., 376). Postulating such relationships then motivates the search for adequate conceptions of truth in this context, since the other relevant representations are linguistic expressions. However, as Goodwin points out, there is also a second sense in which the statement 'contributes to an argument' can be understood, namely as "simply being important to the expression of the argument" (ibid.).[14]

It is this second sense that Goodwin highlights as relevant when considering particular kinds of representations, for example, the functions of words or numerical data in the context of scientific arguments. This second sense of 'contributes to an argument', however, does not require that the entities analysed in this regard have to be capable of bearing truth values. Thus, Goodwin infers that:

> Perini has provided no general philosophical reason to suppose that the visual representations used in science must be understood to bear truth. Recognizing that such representations contribute to scientific discourses in which they occur leaves open the question of how they contribute.
>
> (Goodwin 2009, 377)

Moreover, Goodwin highlights the fact that, even though scientific images might in some instances play the epistemic role that Perini ascribes to them, this does not preclude the possibility that their roles are different on other occasions.

To support his view, Goodwin discusses the example of structural formulas in organic chemistry. He suggests that they can be regarded as diagrams, and thus as visual representations in Perini's sense. Now, with respect to their functional roles in scientific discourse, Goodwin points out two different tasks that they fulfil.

On the one hand, he claims that they are used as *descriptive names* in scientific papers (see ibid., 378). This he derives from their interchangeable use with IUPAC labels[15] (see ibid., 380), that is, labels that are generated by using the rules provided by the nomenclature developed by this union.

On the other hand, Goodwin argues that structural formulas also serve the function of *models* in scientific texts. He writes:

> [o]f course, it is not possible to reproduce physical models of organic compounds on the printed page, and so structural formulas stand in for physical models in chemical discourse. […] Structural formulas – supplemented with some additional conventions – are, on the other

> hand, objects whose characteristics can be used to infer properties of the compounds they denote.
>
> (Goodwin 2009, 381)

Thus, Goodwin thinks that structural formulas can be manipulated to infer information about the chemical compounds that they represent.

Regarded this way, structural formulas as visual representations provide essential information, but it would be wrong to ascribe truth values to them.

> When used as a model it is facts that are true *of*, or *in*, the structural formula that make it so useful in the discourse of organic chemistry. So when a structural formula is used as a model, it is not true or false. Rather, certain claims are true or false in virtue of the structural formula, and these claims license conclusions, perhaps by way of assumed similarity relations that obtain between the relevant objects, about the chemical compounds that it denotes. The role of structural formulas in this context is therefore that of truth maker, not that of truth bearer.
>
> (Goodwin 2009, 388)

From Goodwin's point of view, his example shows that Perini is wrong in assuming that visual representations can make epistemically relevant contributions to scientific discourse only if they are capable of bearing truth values. Contrary to this, he argues that at least some visualisations function as models and, in this sense, make certain claims put forward in this discourse true or false.

Now, there are several questions to be asked about Goodwin's account. Two aspects, also discussed by Perini in her rejoinder to Goodwin's critique (see Perini 2012c), concern, firstly, the scope of his claim and, secondly, the question of whether his example shows what it is supposed to demonstrate.

I will start by discussing Perini's second rejoinder first. She calls into question whether Goodwin's example, namely whether those structural formulas published in papers in organic chemistry, really function as models. She emphasises Goodwin's thesis that it is the possibility of *manipulating* the parts of the model to gain additional knowledge by using it (see ibid., 144). However, as a 2D representation in a scientific text, those structural formulas cannot be manipulated in the sense intended by Goodwin. "All the diagrams Goodwin discusses are static markings on a flat surface. The positions of their parts can't be manipulated" (ibid., 145). In this sense, the analogy that Goodwin tries to establish with regard to models and scientific visualisations does not hold from Perini's point of view.

Nonetheless, she does acknowledge a certain similarity with regard to their epistemic function, but only via a detour through imagination. She states:

> [t]he viewer can imagine a three-dimensional object after viewing the diagram, and then imagine what that three-dimensional object would look

> like if its parts were rotated. Then they could use the same reasoning that was applied to their observations of the actual three-dimensional models after they were manipulated. […] If this is how the diagrams are used, then some model-based reasoning is involved, but the diagram itself is not functioning in the same way as the model in that reasoning process; instead, the imagined compound functions like the model.
>
> (Perini 2012c, 145)

Now, Perini uses this description of how the analogy between inferences made with the aid of models and by using scientific visualisations can be preserved to support two different claims of hers. (1) She points out that, with regard to the particular example discussed by Goodwin, the analogy does not hold. That is, he has not shown that, in this particular instance, scientists were interested in gaining new knowledge via mentally manipulating the presented structural formula. On the contrary, she thinks that the diagrams in question actually work in the sense she suggested earlier, namely "to make a claim about the structures of the isomers" (ibid.). (2) Perini admits that visualisations do have the capacity to function in the way intended by Goodwin and that some of them are also used in this way, namely as tools in visual thinking (see ibid.).

Perini's rejoinder seems convincing. Obviously, visual representations can serve the function of tools of thinking, as has been pointed out in section 3.1.1 of this book. However, it can be questioned (and Perini does so) whether it is this functional role that is intended when distributing the respective visualisation in a scientific paper. More often than not, the presentation of results seems to be relevant, namely the *evidential role* that Goodwin also mentions in his text. This topic will be discussed in due course.

Before going into those details, the analysis should be concluded by also examining Perini's first rejoinder to Goodwin's critique more closely. Although I agree with her first reply, I do have some worries concerning the scope of her and also of Goodwin's claim. Both emphasise the functional roles of the scientific images they discuss in their respective articles as the more or less predominant ones. This also seems to be the rationale why Perini claims, for example, that "[…] the fact that *in some circumstances* scientists use images in ways that are best described as using the image as an object (or description-fitter), doesn't imply that *most* scientific images are used this way" (ibid., 146, my italics). What is missing in both accounts is a more precise analysis of contexts of usage as presented in section 3.1 of this book. Such a more detailed perspective not only reveals that an epistemology of scientific visualisations can accommodate both accounts of functional roles without devaluing the relevance of either of them in the scientific context, but also that, even if the discussion is focused on the explanatory context alone, as both Perini's and Goodwin's are, it has to be acknowledged that visual representations can fulfil different epistemic and non-epistemic functions. It depends on the aim pursued and the mode of the communicative act as well as on the audience involved in it that determine the exact nature of their function. I reject, therefore, the predominance of the respectively identified functional roles of visual representations expressed by Perini and by Goodwin.

Furthermore, it might be helpful to mediate between Perini's and Goodwin's account to bring to mind that there is another close connection between models and visualisations that is often overlooked. Vögtli and Ernst remind us of there being many instances of physical models reproduced in visual representations. The fact that, in the processes of copying such images, people pay less attention to what has been the actual object of reference of their template motivates Vögtli and Ernst to urge their readers to be careful in interpreting the content of visualisations as showing real entities (see Vögtli and Ernst 2007, 47ff.).

To return now to the point that visual representations play an evidential role in scientific discourse. Goodwin puts forward an interesting idea *en passant*. In a footnote of his paper he writes:

> […] consider a piece of physical evidence in a legal trial. Surely it doesn't follow from the fact that this physical evidence plays an important role in the prosecutor's argument that the physical evidence itself must be capable of bearing truth.
>
> (Goodwin 2009, 375, ftn. 2)

He mentions this example to support his initial thesis that certain entities can contribute to arguments, although they are not capable of bearing truth values. From his point of view, such physical pieces of evidence should be regarded as objects that make statements about them true or false. This is the parallel that he wants his readers to draw between this example and his claims about the role of visual representations in the context of scientific arguments.

Although Goodwin's suggestion offers an interesting new perspective on how to conceive of the role of visual representations in science, it still implies that, if scientists want to make use of images in argumentation, they have to formulate statements about them and use the latter in their texts. They still need verbal statements that visual representations can render true or not in order to express their arguments correctly. Yet, contrary to Goodwin, although in accordance with Perini's point of view, the scientific practice of publishing visualisations as parts of scientific papers suggests that scientists do not see the need to translate those visualisations so that they play the roles they are supposed to fulfil. Information given in images is not recorded in the text of the article containing them. Usually there are only references in the text telling the reader to consider the relevant figure in order to get the information relevant to understanding the explanation offered.

This seems to be particularly true with respect to genuine research papers in science. Articles addressing laypeople commonly contain descriptive sections about their visual representations to guide their novice readers in interpreting them correctly. Although scientific images are supposed to play an evidential role in both contexts, their embedding within the written text of the respective article will be different.

Perini is clearly vindicated in pointing out that scientific practices show that visual representations can play an epistemic role in their own right, that is, without prior translation. However, as I am also convinced that Goodman's account does not offer the means suitable to explain the nature of scientific visualisations, I cannot follow Perini's suggestion to regard the latter as truth-bearers as stated in her theoretical framework. Nonetheless, there are alternative ways that might guide our analysis to conclusions similar to those intended by Perini.

Two such strategies will be considered in more detail in the following sections. One is concerned with the *cognitive content* of visual representations. If it can be shown that visualisations do contain such a content, it might be possible to argue that this content works in a way similar to Fregean 'thoughts' when transmitting information. Hence, a subsequent analysis has to focus on the question of whether this kind of content is propositionally structured. If it turns out that it is indeed propositionally structured, a truth-orientated approach, such as the one preferred by Perini, can also be established via this route.

The second strategy, although related to the first one in certain respects, follows a different line of reasoning. Close attention will be paid to the role of *visual perception* when cognitively accessing the information encoded in scientific visualisations. In this context, the epistemic qualities of perception and image perception in particular will be examined. Is knowledge gained via perception and, if so, what kind of knowledge? Is it propositional or non-propositional in kind?

Perini suggests a strategy in a different paper (see Perini 2005c), similar to the idea just sketched, to account for the *evidential role* of scientific images in the explanatory context. Since she also refers to perceiving those visual representations as a relevant step in the process of their cognitive processing, it seems reasonable to combine the analysis of her thesis with a brief review of the discussion of *perception as an epistemic source*.

Yet before going into the details of the two suggested strategies, this section about "visual *arguments*" should be concluded. The level of argumentation as a communicative act will be considered next. Moreover, analysing the topic in a broader perspective such as this is also a consequence of Kjørup's thesis that the object of investigation should be whole communicative acts and not visual representations in isolation if their meaning is to be correctly understood. Taking this suggestion into account, how should visual arguments be conceived?

4.1.3 Giving reasons, drawing conclusions

In this section, a couple of ideas will be used to explain how visual representations can contribute to scientific arguments. My perspective on this topic is guided by insights from semiotics, the philosophy of language and argumentation theory. What analytical tools do these approaches provide to analyse the role of images in this context? To begin with, they permit a better understanding of what the terms ‘argument’ and ‘argumentation’ mean; in particular, what parts they are composed of. Additionally, they will offer some useful information about the questions to which of these parts visual representations can contribute and how.

We will start (1) with a brief analysis of Scholz’s theory of image games. This theory helps us to explain the effects of argumentation on particular images in science. I will call one of these effects a ‘layering of meaning’; that is, subsequent uses of one particular image in different contexts can add new dimensions of meaningfulness to the visual representation at hand. Despite this layering, Scholz’s theory also allows the conclusion that a kind of basic meaning will still be maintained in the encoded content.

If it can be conceded that such a layering of meanings can take place in argumentation, the question arises how best to analyse this process. This (2) will be examined next by deconstructing the act of argumentation including visual elements. As an auxiliary means employed in the investigation, Kjørup’s proposal of pictorial speech acts will be used. This analytic approach will provide the tools to describe the different components of argumentation as a communicative act in science.

Finally (3), this line of reasoning will stress the question of how to conceive of the propositional content inherent in the act of argumentation. To answer this question, I will discuss approaches from argumentation theory dealing with the topic of visual arguments. Two different ways to handle the subject will be considered: on the one hand, some scholars suggest that images do indeed have a propositional content that can account for the task of information transmission in question; on the other, there are philosophers who try to evade the question about propositionality or, respectively, who clearly deny that argumentation presupposes the propositionality of its parts by any means.

Thus, the content-level of visual arguments will finally be returned to. Yet the line of reasoning leading to it points out the possibility of analysing the contributions of visual representations when focusing on the level of argumentation – the communicative act – rather than on the content-level of individual images. To begin with, Scholz’s theory of image games demands closer attention. With this theoretical approach, Scholz suggests the term of image games in close connection with Ludwig Wittgenstein’s theses about *language games*. This latter approach is meant to explain how linguistic expressions acquire their meanings in conversational settings (see Scholz 2011).

As Scholz adopts Wittgenstein’s conception for discussing how meaning is attached to images, it would be reasonable to first point out what he considers to be the essentials of language games. Scholz states that (1) the usage of signs is deeply intertwined with human actions. He points out (2) that words and sentences are not only embedded in contexts of sign usage, but also in cultural contexts. Both contexts are characterised by certain rules that are relevant to the meaning of those linguistic expressions. The thesis is highlighted that (3) to understand linguistic expressions correctly it is necessary to know the rules governing the usage of signs in the different contexts of their usage and within the different cultural contexts.[16] And finally (4) no claims about a presumed *essence* of language games are put forward by Wittgenstein who, on the contrary, defends the thesis that a variety of phenomena subsumed under this label is connected via family resemblance alone (see ibid., 369). These are then the four characteristics of language games on which Scholz relies to transfer Wittgenstein's concept to the pictorial realm and that he uses as a stepping stone to develop his theory of "image games".

As was pointed out in section 2.2.2, Scholz is an adherent of Goodman's theory of depiction. Consequently, he argues that the practice *of using an entity as a picture* implies that this entity fulfils Goodman's definition (see ibid., 371) – that is, images belong to symbol systems that are characterised as syntactically dense and relatively replete. Nothing can be regarded as a picture *per se*. It is due to our treatment of a particular entity that causes it to be thought of subsequently as a picture. However, not any entity can be called an image in that way. In addition to being embedded within the relevant practices, it has to fulfil further conditions, namely the conditions of depiction mentioned by Goodman.

It might be objected that this concept of the term 'image' is somehow in conflict with the anti-essentialist thesis that Scholz wants to transfer from Wittgenstein's account. If all the entities to be called 'images' have to fulfil Goodman's conditions of depiction, their essence not only seems to be clear, but this requirement also considerably restricts what can be called an 'image'. Setting aside this apparently contradictory claim, what else can we learn about Scholz's concept of image games?

Scholz claims that there is a vast variety of different image games (see ibid., 373). Contrary to Wittgenstein, however, he brings in a level of systematising by distinguishing between two different kinds of image games. These two kinds are characterised by their *different directions of fit*. On the one hand, there are image games that imply for their pictorial instances a fit from world to image. Examples are blueprints in architecture or in the engineering sciences (see ibid., 371). On the other hand, there are images that are directed at the world, that is, images that mimic previously present objects of the real world (see ibid., 372).

Two further aspects are of prominent importance with respect to image games. Firstly, Scholz makes clear that one particular image can be used in very different games. For instance, a photograph of a dog can be shown either to inform someone else about what the photographer's pet looks like or it can be meant as a warning, for instance when attached to the fence of the photographer's garden (see ibid., 374). Consequently, *in order to understand an image correctly*, we have to know in which image game it is employed. As Scholz points out (see ibid., 377), particularly regarding a correct historical understanding of certain images, this becomes extremely relevant in addition to background knowledge about the cultural specifics and practices.

Secondly, and as a consequence of this close connection between purposes of usage and meaning, there is (or can be) a distinction between the context of producing an image and of its subsequent usages (see ibid., 372). This distinction implies not only a change in meaning due to the different purposes involved in using the image at hand, but also that completely different individuals might interact in both contexts. Thus, many more agents can be involved than a simplistic focus on the context of image production alone suggests.

Now, Scholz thinks that many image games are related to communicative purposes (see ibid., 373). I would maintain, rather, that *all* of them are somehow related to communication. This point of view is a consequence of how the term 'communication' is understood. I prefer a broad concept here, obviously broader than the one used by Scholz. The concept used here is based on ideas propounded by Paul Watzlawick and his colleagues. They suggest that all kinds of behaviour in social settings can be interpreted as communicative acts and that, as we cannot stop behaving, we will never cease communicating in those contexts (see Watzlawick, Beavin and Jackson 1974, 51).

Although Scholz relies on Goodman's theory of depiction, which has already been pointed out as being unsuitable in the context of scientific images, his concept of image games is nevertheless very useful in the attempt to clarify the role of visualisations in scientific communication and, in particular, in scientific argumentation. The theory of image games makes clear that there are more aspects to consider when trying to understand what is meant by a particular image in a communicative context than its encoded content alone.

Leo Groarke's conceptual theses about argumentation pave the way for further analysis. He claims that "'[a]rgumentation' includes not only arguments, but also the broader dialogue, discussion and disagreement in which arguments are embedded. Acts of arguing attempt to rationally establish some conclusion by providing evidence in its favour" (Groarke 2015, 135). Thus, regarding argumentation as a communicative act[17] permits utilising the theory of image games and, hence, disentangling correctly what has been called a 'layering of meanings'. Such a layering is the result of a multiple usage of one particular image. In such a case, there is the genuine meaning encoded into the visual representation by its producer. This basic meaning, however, will be covered (at least partly) by layers of meaning superimposed on the genuine one by subsequent users. Making use of visual representations in image games can, at least, add a second meaning to what has genuinely been encoded into the visual format, and this second meaning might change due to the different games played with the aid of this particular image. A compilation of meanings, acquired in different image games, might also be possible, but would be rather an exception than an example of common practice.

Nevertheless, adding layers of meaning in image games to what the visual representation was genuinely supposed to express by its producer is the reason that Scholz urges us to reconstruct the genuine image game and cultural surroundings if visual representations are to be correctly understood. Important dimensions of meaningfulness would simply be overlooked if the focus were solely on the context of production. Hence, the theory of image games permits discovering what additional levels of meaning images can acquire by being used in argumentation. The question of how exactly images play a role in argumentation is answered in the second part of the analysis, which is concerned with ways to deconstruct the act of argumentation to see if and how visual representations contribute to its different parts.

Kjørup makes us aware that understanding visual representations correctly has to take into account the whole communicative act, not the image in isolation (see Kjørup 1978, 57). Moreover, by taking *speech act theory* as the relevant paradigm, he makes clear that pictorial speech acts are composed of different parts, namely an illocutionary, a locutionary and the propositional act (or content, see ibid., 61). Taking these levels into account and adding the perlocutionary act offers us the means to show at what levels visual representations can make contributions to scientific arguments.

To begin with, the significance of these sub-acts in speech act theory should be briefly summarised: the locutionary act concerns the uttering of words or, with regard to visual representations, the showing of images in conversational contexts. The illocutionary act is about the kind of act performed, such as warning somebody by showing the image or simply informing her of the appearance of what is depicted, etc. The propositional act is about encoding the basic information, for instance by drawing a certain figure or taking a photograph (see ibid.). And finally, the perlocutionary act is about the effect intended on the recipient, for example, evoking a particular emotion or convincing the recipient of a certain proposition.

Kjørup tries to spell out rules for all of these sub-acts when images are utilised in communicative contexts (see ibid., 61ff.). He points out that the *context of usage* is important both to fix the reference of a particular visual representation (see ibid., 58) and to determine what particular illocutionary act is performed by using a certain image (see ibid., 65). Even a photograph seems to presuppose some background knowledge about what is depicted in order to discern exactly to what it refers. For instance, it is only by reading the caption accompanying Figure 2.15 that we come to know that it shows lava flows on Olympus Mons on Mars. Without this additional information, we would most probably be unable to interpret to what this photograph refers.

Moreover, Kjørup discusses particular illocutionary acts that can be performed with the aid of visual representations. For example, he tries to establish the rules governing the illocutionary act of "illustration" (see ibid., 66ff.), which is particularly interesting with respect to the intertwining of text and image that plays a major role in this case in order for it to be successfully performed.

Applying these ideas to the broader context of scientific argumentation, it seems reasonable to assume that *argumentation* can be similarly subdivided into particular acts, as suggested above with respect to speech acts – although one might object that arguments are composed of *assertions* and that it is this kind of act that should be analysed when discussing the nature of arguments. Correct though this might be, the relevant level of analysis still seems to be about arguments and not about assertions. Moreover, to a certain degree it is also possible to transfer the subunits of speech act theory to arguments. How does this work and why is this of relevance when theorising about visual representations in scientific arguments?

I shall start by investigating the possibility of transferring the units of analysis to the context of argumentation. When arguments have to be uttered or otherwise employed, a locutionary act occurs. Arguments entail certain information that the speaker will encode them in a certain way – the propositional act. They are meant to transmit information by offering reasons to believe in a certain conclusion supported by them that could be called the illocutionary act. This transmission of information can then be connected to the various intentional aims of the speaker. She might want to transmit knowledge, she might want to ponder on the consequences of certain hypotheses herself, or she might want to solve a particular dispute. This last option, for example, is put forward by Groarke as the aim of argumentation. He attempts to clarify the nature of 'arguments' by writing that:

> I define an argument as a standpoint (a conclusion) backed by reasons (premises) offered in support of it. In a typical case of arguing, arguments are an attempt to resolve disagreement […], though they may also function as an attempt to avoid disagreement by securely establishing some belief. I will understand an act of arguing as an attempt to use premises and conclusions to resolve some disagreement or potential disagreement.
>
> (Groarke 2015, 134f.)

Finally, arguments are supposed to convince the recipient about what has been transmitted by argumentative means; in this case, this could be regarded as the perlocutionary act. This subdivision of arguments is relevant in the current context because quandaries about cases of using visual representations as *parts* of scientific arguments can apparently best be understood as a *consequence of their contributing to different sub-acts of argumentation*. Making use of visualisations in the context of scientific argumentation does not necessarily imply that they are meant to entail information relevant to the argument at hand, that is, they do not have to be parts of the propositional act. They can also be used as a means to support the perlocutionary act. Clearly, visualisations are used to support the persuasive power of arguments in many instances. This functional role *can* be correlated with transmitting additional information such as evidential data. Visual representations might also be used to present data in an organised way that makes correlations salient. However, particularly in popular science, visualisations simply might also be used because of their persuasive and emotional power and, in this sense, have to be evaluated cautiously if the epistemic dimension is of interest.

Finally, it can be asked whether visualisations can also be used as means to perform the locutionary act. Is it possible to 'utter' an argument simply by showing an image? Clarifying this question seems to be particularly relevant in contexts where the contending parties introduce images in an ongoing debate in which, say, party Y is urged to counter an argumentative move made by party X by also making use of images to support her position. A telling example of this kind is discussed by Randall A. Lake and Barbara A. Pickering. Their case study is about the debate between anti-abortionists and pro-abortionists in the United States (see Lake and Pickering 1998) and will be discussed in some detail below. Lake and Pickering's account will be discussed in some detail below. For the moment it will suffice to note that their example makes it particularly clear that there are instances where contending parties seemingly have no other choice than to make use of visual representations in their argumentation.

Let us now come to the third part of my analysis, namely to the question of whether visual representations can also play a part with respect to transmitting propositional contents. Groarke, for example, approaches this topic rather carefully by claiming that:

> [t]he kinds of examples that motivate me are acts of arguing that involve pictures, maps, sounds, diagrams, smells, video clips, and other non-verbal phenomena which are not propositional in the way that verbal statements are (though it bears noting that the relationship between sentences and propositions is itself a matter of much controversy).
>
> (Groarke 2015, 135)

Obviously, he thinks that non-verbal elements can also function as premises and conclusions in argumentation. However, he does not try to pin down the claim that these non-verbal elements are propositional in the sense claimed for sentences.

A different approach is suggested by Lake and Pickering. They examine the possibility of visual arguments by taking a look at films. They do not want to analyse arguments of mixed media, but images as exclusively visual arguments. At least, this is what they attempt to investigate, although in the end they admit that their case study actually shows results only for a "mixed-media environment" (Lake and Pickering 1998, 91) – which is not surprising since they focus on films as their object of research. However, what Lake and Pickering might regard as a shortcoming in their analysis becomes a virtue in the context of our current discussion.

In their analysis, they try to show in what sense images can be said *to refute* one another. The authors start with the assumption that visual representations do not have a propositionally structured content (see ibid., 81). Moreover, they regard the ability to refute as essential to whatever kind of representation is used in argumentative contexts. In contrast to Perini, Lake and Pickering deny that images can be bearers of truth values, but they nonetheless think that images can be used in argumentative contexts since they can *refute* each other.

They point out three different ways how such a refutation can be achieved by visual means, namely:

> (1) through *dissection*, in which an image is 'broken down' discursively, its component parts named and its relations analyzed, thereby opening the image to refutation via traditional (discursive) argumentative means; (2) through *substitution*, in which one image is replaced within a larger visual frame by a different image with an opposing polarity; and (3) through *transformation*, in which an image is recontextualized in a new visual frame, such that its polarity is modified or reversed through association with different images.
>
> (Lake and Pickering 1998, 81f.)

Lake and Pickering discuss these assumptions by analysing films used by opposing parties in the dispute about abortion in the US. They show how anti-abortionists and people defending women's rights regarding abortion make use of different films that become part of the debate and are used in such a way that these films can be said to refute one another.

In particular, they discuss how the anti-abortionist film *The Silent Scream (SS)* is dissected within another film (*A Planned Parenthood Response to 'Silent Scream' (PPR)*) produced by the contending party. This is meant as an example of the first strategy of refutation. For instance, the plastic model used in *SS* to demonstrate the developmental state of the foetus is criticised as inappropriate in scale. Furthermore, the slow-motion technique used in *SS* to create the impression of a very calm and secure environment for the foetus in the womb is highlighted as a manipulative means in *PPR*. They make clear that the *SS* film-makers used slow motion to manipulate the recipients' impressions by visually demonstrating the frame-by-frame changes visible in their film (see ibid., 86). Beyond that, *PPR* also makes use of the strategy of substitution. Whereas *SS* focuses on the foetus as a victim and presents pregnant women suffering passively after abortions, *PPR* shows women as rational and active decision-makers. "It replaces images of women as passive and pregnant with images of women as active professionals" (ibid., 87). Finally, *PPR* also offers an example of the last strategy of refutation, namely transformation. Key images of *SS* are presented here in a different visual frame. For example, a specialist is shown watching *SS* on a TV screen, commenting critically on what is shown (see ibid.).

What becomes clear in Lake and Pickering's analysis is that participants in a controversy not only have to pay attention to their opponents' verbal statements, but also have to operate in a visual way if their rivals make use of visual representations in the course of the debate. One reason for this obvious necessity might be found in the commonly stated *persuasive power* of images.[18] Lake and Pickering offer a much stronger reason when indirectly referring to the *evidential role* of visual representations. Interpreting the anti-abortionists' communicative intention to use films in the debate, they conclude that for these people films even have the status of *proofs*.[19] At the end of their paper, Lake and Pickering state that:

> [i]nterestingly, SS (and anti-abortion rhetoric generally) implicitly adopts the view […] that pictures *cannot* argue, and adapts this view to ideological ends; that is, it contends that images of the fetus are *beyond* argument and constitute *irrefutable* proof of the fetus' humanity.
>
> (Lake and Pickering 1998, 91)

More precisely, the thesis that is supposed to be proven visually by *SS* is that "the fetus is an unborn 'child' and that abortion therefore must be murder" (ibid., 84). Obviously, Lake and Pickering regard 'argumentation' as an exchange of reasons in this context. If one side achieves for its thesis the status of a proof, a continuing exchange would make no sense, as apparently no question is left for further discussion.

Lake and Pickering contrast this claim about what anti-abortionists attempt to achieve by showing their film with what the authors think is the underlying assumption of the second party's way to make use of films in this context.

> In contrast, PPR implicitly adopts the view […] that pictures *can* argue, and adapts this view to contrary ideological purposes; that is, it contends that images of the fetus are *only* argumentative, are *susceptible* to refutation, and constitute *misleading* evidence of the fetus' humanity.
>
> (Lake and Pickering 1998, 91)

Lake and Pickering elaborately show different strategies of utilising films – and thus of visual representations – in an already highly charged emotional debate. They point out the dynamics of the debate that played a role in producing and making certain visual representations popular. In particular, it becomes clear that, because of the persuasive power of images, the contending parties were simply not able to ignore this shift in representational means in the debate and stick to an exchange of linguistic arguments. They had to bring into play something that could deal with this persuasive capability of images. Doing so, however, does not necessarily imply that in such instances *pathos* is given priority to *logos*, as critics usually object. Contrary to this, Lake and Pickering point out that refuting the visual representation of *The Silent Scream* also means presenting a detailed and careful analysis of what is shown in this film and making clear how and why those images were produced. These analytical steps are accompanied by visualisations that are meant not only to support the verbally but also the visually presented explanations of experts (see ibid., 86). For example, the expert's claim that it is neurologically impossible that the foetus screams inside its mother's womb is supported by images showing the development of the human brain. At the relevant stage, it is neurologically impossible that the brain of the foetus is able to register alarm (see ibid.). This illustrates the point that making use of images in argumentation does not necessarily imply dramatisation and appeals to emotional stimuli. They can also be used in an explanatory and/or evidential way.

Beyond that Lake and Pickering's analysis also shows how images can make contributions to the different sub-acts of argumentation.

- Visualisations were necessary to utter the argument (locutionary act). The examples in this context are films. Moreover, visual representations – such as the ultrasound images of the foetus, or images of the developmental stages of the foetus's brain – are displayed within this audiovisual medium.
- Images were used as persuasive means (perlocutionary act). For example, the ultrasound images of the apparently screaming foetus and its apparent attempts to avoid the abortion are supposed to provoke feelings of sorrow and compassion amongst the recipients.
- Visual representations entail certain information (propositional act). The *PPR* film-makers, for example, demonstrate visually that their opponents produced a propaganda-film making secret use of slow-motion techniques to provoke certain emotions.
- Finally, images were brought into play to *securely establish some belief* – to use Groarke's words (see Groarke 2015, 135) – (illocutionary act). By showing their films, both parties try to convince an audience of their respective opinion, namely that abortion is either murder or that it is not.

What remains to be shown is how to deal with the thesis that visual representations can provide propositional knowledge, although it is disputed by traditionalists that images are propositionally structured. Two further proposals of how to conceive of visualisations in the argumentative context should therefore be examined more closely at this point.

To begin with, (1) Axel Arturo Barceló Aspeitia suggests taking them as instances of what he calls "heterogenous arguments, i.e. arguments that are not conveyed through a single medium, but instead make use of both verbal and visual resources" (Barceló Aspeitia 2012, 356). He thinks that, in these contexts, visualisations can indeed make proper contributions which "can be either sub-propositional (i.e. properties and functions that, properly combined with information conveyed through other means, like words, or available in the context, can yield full propositions) or fully propositional" (ibid.). Thus, Barceló Aspeitia is convinced, like Perini, that visual representations can entail propositionally structured information. Contrary to her conviction, however, he does not claim that images can be bearers of truth values. By analogical reasoning, he compares heterogenous arguments with sub-sentential ones. The latter contain fragmentary statements, either as premises or as conclusions, and are nonetheless understood as transmitting full propositions (see ibid., 357). In such cases, the context yields the missing information. This contextual information enables the hearer to understand what was meant by the sub-sentential argument. Barceló Aspeitia thinks that, just as language can be used in a fragmentary way to transmit complete propositions, images can also play this functional role. Thus, he tries to show how, in certain instances, image and text work together to transmit the information intended by the speaker or writer.

Barceló Aspeitia points out that it is common practice to use a combination of different modes of representation – or media, as he calls them. The examples he mentions are wanted signs, store catalogues and advertisements. We do not usually have any difficulty understanding that the combination of an image and a numerically expressed price tells us that a certain item is meant to be sold for a certain amount of money (see ibid., 360). In this way, image and text interact to complete the message.

Yet it might be objected, as Barceló Aspeitia points out, that this information transmission is only possible if the proposition in question is reconstructed verbally by the respective recipient (see ibid.). Contrary to such an assumption, however, he defends the thesis that paraphrasing is not necessary. As a rationale for this claim, he refers to the difficulty of translating the non-verbal elements in a precise and unambiguous manner. He concludes that "[p]recisely because it is not always possible to translate heterogenous arguments into verbal ones, it is very unlikely that that is what happens every time we interpret heterogenous arguments" (ibid., 361). Nonetheless, the mere possibility of highlighting certain translations as more adequate than others and, furthermore, of ruling out certain sentences as completely inadequate as translation demonstrate, from his point of view, that visual representations convey propositional content – that is, a content being used as a benchmark to assess the adequacy of certain translations.

An example is provided by the successful detection of gravitational waves mentioned in the introduction to this book. A crucial part of the argument that a successful detection had been achieved was that two measurement devices registered the signal independently and thereby raised the statistical significance of the evidential status of the event registered. This claim is supported by the fact that the two diagrams (see Figure 1.2) showing the registered data match to a significant degree. This seems to be the usual way to translate visual representations, such as the diagrams in this example, in the context of a heterogenous argument. However, the fit between both diagrams claimed here is doubtless only a rough approximation to what is visually conveyed. Yet the conflation of the two diagrams also shows that a claim such as "The LIGO project at Hanford registered completely different data from the LIGO project at Livingston" would not be an admissible translation of these diagrams.

Barceló Aspeitia comes to a positive result when considering the question of whether visual representations can transmit propositional content.

> Thus I conclude that the contribution images make to this kind of argumentation is substantial and direct: exploiting information from the context, they provide information necessary for the communication of the propositions that play the roles of premises and conclusion. Furthermore, they achieve this directly, without the need of verbalization.
>
> (Barceló Aspeitia 2012, 365)

Yet contrary to some conceptions of ‘proposition’, he also defends the thesis that propositions are not linguistic entities (see ibid.). They *can* be transmitted linguistically, but this can also be achieved by using other kinds of representations. Thus, what alters the scales here is the question of how exactly to conceive of ‘propositions’ – and Barceló Aspeitia at least partly removes this concept from an assumed close connection to verbal expressions. That is, his considerations undermine the assumption of a need to express propositions in verbal statements right from the start, or at least the possibility of translating the content transmitted by other representational means completely into verbal statements. This interesting move will be scrutinised in more detail in due course when analysing the nature of the *cognitive content* of visual representations below.

The second strategy (2) to deal with visualisations in argumentative contexts that will be discussed here is Groarke’s approach to the topic. His proposal about “multimodal arguments” offers a different perspective with regard to the relevance of propositionality in the context of argumentation (see Groarke 2015). He agrees with Perini and Barceló Aspeitia that visual representations can be regarded as proper parts of arguments. Furthermore, Groarke defends the claim that these parts do not have to be propositionally structured to play the epistemic roles they are supposed to fulfil in those contexts (see ibid., 135). He attempts to broaden the concept of argumentation in an even more wide-ranging sense than, for example, Barceló Aspeitia. He writes: “[t]he classical model of argument understands arguments to be entities made up of words and sentences. In using other modes of arguing, arguers build arguments from other kinds of ingredients – pictures, diagrams, non-verbal sounds, tastes, and so on” (ibid., 140). Thus, Groarke regards a broader class of “ingredients”, as he calls them, as possible candidates in argumentative structures. As a result, his conception by far exceeds my attempt to show how the three modes of representation – linguistic, visual and numerical – interact in the context of scientific argumentation. Groarke’s broader perspective, moreover, also permits the detection of an even closer connection between visual representation, observations and sense perception as an epistemic source.

What exactly does Groarke suggest? Having pointed out that there are a lot of different “ingredients” a speaker might utilise in her argument, he proceeds by defining different modes and sub-modes of an argument along the lines of these ingredients. In order to analyse these multimodal arguments, he suggests the usage of a "Key Component" (KC) table (see ibid., 135). This table summarises the different components used in a particular argument by displaying in a first column "acts of arguing" (actions such as the utterance of claims, the display of visual data, etc.), the structural parts of the argument (premises and conclusion) in a second, and, finally, in a third column the mode used to express the different parts (visual, verbal, etc.). Although Groarke admits that using such a table to analyse multimodal arguments also means interpreting the different components to some extent (see ibid., 139), this method nonetheless permits a more faithful reconstruction than does a mere verbal translation of the relevant parts. Groarke's suggestion seems to be a useful addition to the traditional methods of argument-reconstruction in verbal forms employed to analyse their validity and conclusiveness.

Even more importantly, however, he points out that not only visual representations but also actual visual demonstrations can be parts of argumentation (see ibid., 148f.) – respectively, components that we perceive by our other senses such as smells or sounds (see ibid., 149f.). All of them are instances of using *perception* as an epistemic source. In order to better understand in what sense it can be said that these instances contribute to argumentation by adding information to premises and conclusions, the epistemic capacities of perception should be examined more closely. How do they work and what kind of knowledge (propositional or non-propositional) do they yield?

To sum this up, both, Barceló Aspeitia and Groarke try to pave the way for a more moderate conception of argumentation which would justify Perini's observation that it seems to be common practice to make use of other (in particular visual) components in the context of scientific arguments. Nonetheless, both accounts also raise the question of how (and what kind of) information is extracted from these different components to be employed in argumentation. This leads to a discussion of perception as an epistemic source and is closely connected to the question about what kind of content we cognitively access when deciphering information encoded in visual representations. Both questions will be considered in section 4.2.

4.1.4 Interim results: what can be learnt from argumentation theory?

In the previous sections, a closer examination was made of the possibility of visual arguments. This term is used in the debate to refer both to arguments that contain visual representations as (parts of) premises or conclusions, and to images that are supposed to express a complete argument. Perini has pointed out the tension between, on the one hand, scientists' practices of making extensive usage of visual representations in epistemic contexts of this sort and their obvious conviction that visualisations can undoubtedly fulfil the epistemic tasks they are supposed to perform and, on the other, the tendency of philosophers to ignore them or to hold them to be epistemically impotent.

It was argued above that this ignorance is at least partly a result of the linguistic turn at the beginning of the developmental history of analytical philosophy. This focus on language still dominates studies of this discipline and hence approaches connected to this field, such as the philosophy of science. In particular, arguments – that serve, amongst others, as means to transmit and defend scientific hypotheses – are typically regarded as linguistic entities. Moreover, as the discussion of this traditional point of view has shown, the emphasis on verbal expressions is also related to the question of what kinds of representations are suitable candidates in logical operations. In particular, entailment relations and the capacity to bear truth values are of relevance when it comes to (scientific) arguments. Both features, however, are associated with linguistic expressions in the Fregean tradition. Thus, visual representations are dismissed in this context as apparently belonging to the wrong kind of representation.

At best, people defending the traditional point of view in philosophy would call for a translation of information potentially contributed by visual representations to linguistic arguments. Thus, they think that proper contributions are only possible via a paraphrasing – a method that is supposed to take place in the recipient's mind – if it is not made explicit in the relevant publication. It is interesting to note that the demand of such a paraphrasing into linguistic expressions is not restricted to the realm of scientific argumentation.

Exactly the same sort of discussion can be found, for example, with respect to the epistemic functions of *thought experiments* (see e.g. Brown and Fehige 2011, sect. 3.2).[20] Here, too, the necessity to paraphrase the content presented visually is discussed to make use of it within the epistemic process in which it appears. With regard to thought experiments, this similarity to the above discussion comes as no surprise because the approach defended by John D. Norton in this respect is simply that "thought experiments in science are merely picturesque *argumentation*" (Norton 2004, 1142, my italics). Thus, Norton not only draws an analogy between the epistemic function of thought experiments and scientific arguments, he actually affords them parity. From his point of view, arguments can replace thought experiments without losing essential information (see Norton 1996, 336). In developing this thesis, he tries to make a case against James Robert Brown's ideas on the topic. Contrary to Norton, Brown thinks that the picturesque element of thought experiments is not simply reducible to (verbal) arguments. He states that thought experiments work epistemically *because* they are visual in certain respects. In particular, he emphasises the relevance of perceptually accessing the content of thought experiments. Of course, such a conception presupposes certain hypotheses about the nature of phenomena, their correlations (laws of nature) and the way these essential facts are understood.

To start with, from an ontological point of view, Brown defends a Platonist approach. That is, he thinks that abstract objects, such as mathematical objects, exist independently of human beings and do not belong to the realm of time and space. Moreover, he assumes that laws of nature are relations between properties. These relations are regarded as abstract objects as defined above (see Brown 2004, 1130f.). But how can we grasp these laws of nature? This is the point where it is of relevance that thought experiments are *visual* entities. Brown is convinced that we are able to *perceive* the laws of nature when visually engaging in thought experiments. He writes:

> [a]ccording to mathematical Platonism we can perceive the abstract entities of mathematics. Not all, of course, but we do have intuitions of some of them. So, it's possible to perceive abstract entities, at least some. Usually we learn laws empirically, by seeing instances. But laws are abstract entities, so they could be perceivable, too. How could we have an intuition of a law of nature? The obvious thing to conjecture is that we grasp them via thought experiments. Laws and numbers are both outside of space and time. If we can see one, then we should be able to see the other. Thought experiments are telescopes into the abstract realm.
>
> (Brown 2004, 1131)

Translating thought experiments into verbal arguments would then imply cutting off the ability to epistemically access the relevant content that they reveal to the recipient. At least our understanding of the relevant correlations would be hampered to a certain degree.

Brown's ideas on the topic undoubtedly deserve closer attention in order to understand correctly what is implied by his different hypotheses. In particular, his approach to regarding thought experiments as perceptual tools to grasp laws of nature as abstract objects is obviously not an easily handled topic. Consequently, the discussion of this account here is admittedly rather brief, as I will not go into the details of Platonism; nonetheless, the controversy between Brown and Norton is worth mentioning in the context of the current discussion. It makes explicit an important question already present above in the discussion of visual arguments in science, namely what a translation of possible contents of thought experiments into (verbal) arguments would imply.

The question about the consequences of a translation reveals different dimensions of the topic that should be kept apart. (1) If a translation is possible, then there is a cognitive content of some kind present in both instances. Are there particular difficulties with regard to such a translation? If there are, this might mean, in a negative sense, (2) that one of these representational means is inferior to the other in performing a certain epistemic task. Ambiguities, for example, might cause problems in translations. If precision is required in the situation at hand, representations that do not meet this standard seem to be inappropriate tools to serve the respective purpose. This also shows that (3) evaluations of inferiority and superiority are not absolute. They are relative, depending on the context of usage and the task to be performed with the aid of representational means. Nonetheless, there might be contexts (4) in which our perceptual sense is of particular use in grasping certain information, as evolution has emphasised its development in human beings. Vision is our primary sense to perceive, to cognitively access the world. It should not come as a surprise that images, which allow us to make use of our visual sense to decode them, are easier to handle in the epistemic process than other modes of representation. Finally (5), there might be certain aspects that can be accessed via perception only (this is what seems to lie at the heart of Brown's ideas about thought experiments) and thus undermine the suggestion of translating visually presented information into verbal information in any possible context.

These five theses constitute the stepping stones to the next questions. Do visual representations contain a cognitive content? And, if so, is it similar to the propositional content of verbal expressions? If it is similar, this might provide a clue to rethinking the concept of propositions as currently in use in the philosophical community. The tight linkage to linguistic expressions may have to be considered anew because propositional content can also be transmitted by visual means. However, if it turns out that, although the content entailed in visual representations is not similar to the nature of the alleged propositional content in the Fregean tradition, it can nevertheless be shown that at least some visual representations are epistemically potent, this might then be taken as a clue to reconsider the thesis that epistemic usefulness is exclusively tied to propositional content.

The discussion of these two alternative approaches on how best to explain the epistemic potentiality of images in the context of scientific arguments naturally takes its course by analysing perception as an epistemic source. It is through perception that the content of visual representations is cognitively accessed. Clarifying this route of access will thus also contribute to an understanding of how visual representations may be epistemically effective. This, then, is what will be analysed in more detail in the following section.

4.2 The cognitive content of visual representations

Making use of visual representations in scientific arguments in the way Perini explains this process, namely that scientists "describe figures as supporting, or as expressing, the conclusion of an article" (Perini 2010, 134), implies a particular attitude towards those representational means. Scientists seem to assume that those images entail certain information and, additionally, that they are able to transmit this information in an appropriate way. These attitudes towards visual representations in science are one of the main reasons supporting the initial claim that scientific images can best be regarded as signs.

Perini takes this observation about communicative practices in science and the place of visual means therein to demand that "[w]e [i.e. philosophers of science, N.M.] need to take a more fundamental approach to understand what kind of contents visual representations convey, and how they do so" (ibid., 135). Thus, there is a need for "a more specific account of visual representations as communication tools – a theory of signs or a semiotics of visual representations" (ibid.), as she expresses it. In this section, an approach to account for this capability of visual representations to serve as communicative tools and will proceed as follows.

Firstly, a start can be made by focusing on the capacity of visual representations as *content providers* in scientific arguments. It is necessary to analyse in more detail in what sense this capacity can be accounted for and what exactly the nature of the content is that can be transmitted via visual representations. This topic is connected with considerations about translatability and the limits to what is expressible by certain representational means. Certain theses of this sort have already appeared in section 2.2 of this book. The consideration now must be why certain characteristics of visual representations do not apparently preclude the latter from being used in scientific communication, although philosophers tend to regard them as shortcomings.

Moreover, taking seriously the possibility of *translations* from one representational means into another raises the question of whether this transfer of information only works in some directions but not in others. Taking into account the initial distinction made earlier between numerical, linguistic and visual representations, it might be argued that certain translations will imply a loss of information, which might lead us to the assumption that one of those representational means is more ontologically and epistemologically basic than the others. That is, although all information can be encoded in a (visual) representational means when transferred into another medium, the content provided might lose particular pieces of information in that process. In section 3.1.1 of this book, we have already come across the puzzle that digital images present when discussing the epistemic status of scientific visualisations. With regard to digital images, the question arose of whether numerical data should be considered as the more basic kind of representation, as, obviously, digital images are rendered in such data sets. In the following, such an apparent *reducibility thesis* will be examined more thoroughly.

Closely connected to this issue of reducibility is the question of how exactly to conceive of the content of visual representations in science, that is, the question of whether it is propositionally structured or not. What links this to the discussion of reducibility is the following consideration: although there are many different accounts of what the term 'proposition' exactly means,[21] one aspect that is commonly accepted is that propositions are expressible by linguistic sentences. At least in this way, propositions are tied to language, although they themselves do not necessarily have to be linguistic in kind. A corollary of this is that if the content contained in and transmitted via visual representations is non-propositional in certain respects, it cannot be translated and thus is not reducible to linguistic expressions without a loss of information.

Secondly, the topic of *perception as an epistemic source* will be discussed in order to come to tackle this question about the assumed propositional or non-propositional content of scientific images. Obviously, the information that is presented via visual representations has to be perceived, that is, their content has to be cognitively accessed by vision – the primary human sense. It does not therefore seem far-fetched to assume that the epistemic mechanisms of perception will also disclose something about the special case of image perception, i.e. the decoding process of information presented visually. A closer look at the epistemological debate about perception in general thereby reveals an interesting fact concerning the question of propositions. On the one hand, contemporary philosophers seem to have no particular problem in regarding perception as an epistemic source, i.e. as a source of propositional knowledge. On the other hand, there is no consensus about the content of perception and how exactly it features in processes of justification concerning perceptual beliefs.[22] This presents a difficulty similar to the case of visual representations in science. Although knowledge claims based on visually transmitted information (either via perceiving images or by perceptual experiences of other entities in the world) are commonly accepted, there is a dispute over whether the content of images is propositionally structured or not. Contrary to the case of everyday perception, this latter question is employed to undermine claims concerning the epistemic capabilities of visual representations in communicative contexts, whereas a potential non-propositional structure of perceptual experience in general is not usually indicated as a particularly serious obstacle to gaining knowledge via perception. This discrepancy between the two cases seems to be worth closer investigation.

It can be assumed that this difference is a consequence of the initially defended thesis that scientific images can best be regarded as *signs*. Taking this claim seriously, one might object that, particularly in the context of scientific communication, those signs cannot simply be perceived in order to decipher their content, but that background knowledge is necessary to interpret them correctly. It might be argued that permitting the thesis that non-propositional content plays a significant part in visual discourse would clash with the communicative aims of transmitting precise information and clear messages. The compatibility of the claims that scientific images are signs and that perception is the primary way to decipher their content will therefore be analysed thirdly. Before discussing these difficulties, a start can be made by scrutinising the content characteristics of visual representations in science in more detail.

4.2.1 Content translatability and the reducibility thesis

In this section, the question will be investigated whether it can be stated that visual representations possess a content that works similar to Fregean

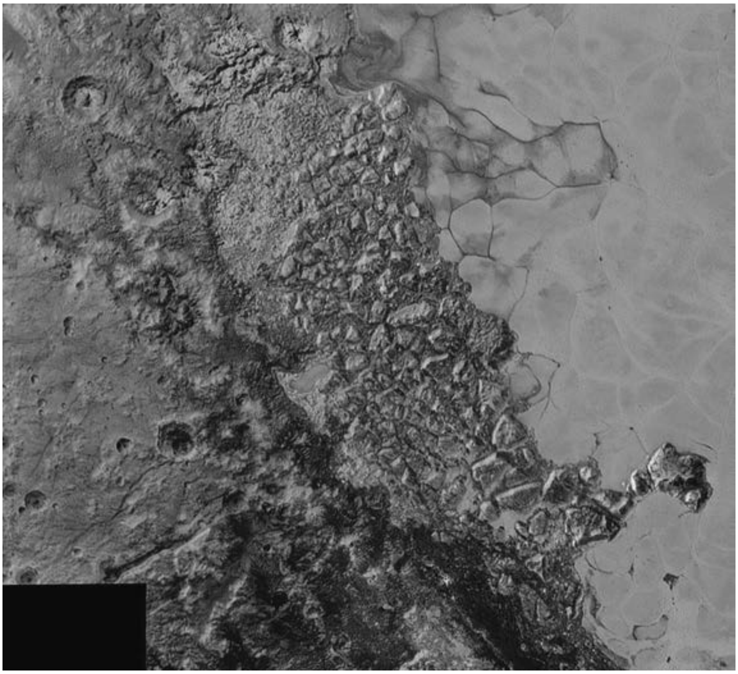

Figure 4.3 Image of Pluto's vast, icy surface. This part of its surface is informally called Sputnik Planum. The image was taken from a distance of 50,000 miles (80,000 kilometres) as *New Horizons* flew past Pluto on July 14, 2015.

Source: Southwest Research Institute, www.nasa.gov/image-feature/image-of-plutos-vast-icy-plain-informally-called-sputnik-planum

'thoughts' in linguistic expressions, that is, whether they have a content that human observers can cognitively access and process to gain knowledge or not. My approach to this topic is via an analysis of content translatability from one representational means to another. An example will illustrate what is at issue here.

In 2015, after a nine-year voyage, the NASA spacecraft *New Horizons*[23] finally reached its first mission destination, the dwarf planet Pluto and its system of satellites. Since its arrival, the space probe has started taking and transmitting photographs of Pluto (see Figure 4.3) and its satellites. Of course, these are digital images, not analogue photographs. What is transmitted to Earth are digital data that allow the corresponding image to be rendered when the data have been received. In this case, a translation between the numerical and visual mode of representation apparently works without a loss of information.

This kind of translatability is not very surprising, because digital photography works by storing information detected by a charge-coupled device

(CCD) sensor in binary units that allow the reconstruction of visual information as a picture later on. Interestingly, this process also works in reverse. That is, starting with an analogue image, we can transfer it into bits and bytes by simply scanning it, and it is not only images that we digitalise in this way but texts, that is, written language, as well. Moreover, oral language can also be recorded and digitally stored. Thus, switching back and forth between numerical data on one side and all other modes of representations on the other seems to be fairly unproblematic. Again, this is not very surprising as this is how information-technology devices work.

Regarded in this way, then, no representational means seems to be more basic than numbers, or rather 'digital units', as even numbers are reduced to bits in IT contexts, that is, to 'basic units of information'. These units are expressed by binary representations such as the commonly used 0–1 schema. However, they could also be represented quite differently.

Now, what does this translatability of all three kinds of representation to digital units mean with regard to the question of the content provided by visual representations and its usability in scientific epistemic discourse? Firstly, it shows that, at least in a trivial sense, *there is information* contained in all representational means that can be transferred from one medium to another, namely information about the respective medium itself. However, it is the representational relation involved that is of interest here, namely the question of whether what can be transferred in such translation processes can go beyond this trivial kind of information. That this is at least sometimes the case becomes clear when regarding the process of digitalisation in reverse, as Zachary C. Irving does. He states that:

> [c]omputer simulations and other computerized instruments are interesting case studies because they output data sets that can, in principle, be represented in many different styles (e.g. numerically or visually). Since each of these stylistically distinct outputs represents the same data set, they should have the same content and thus, *prima facie*, be intersubstitutable in whatever scientific argument they are used without a change in soundness.
>
> (Irving 2011, 775)

Does this mean that these different representational variants of the basic content can then be used interchangeably in communicative contexts?

Such an assumption seems to be immediately blocked when human beings are considered an essential part of the epistemic process under discussion. This is also the objection that Irving raises. Although it might be possible to transfer all kinds of information into digital units, it would be senseless to present these sequences of bits and bytes in scientific arguments because we would simply not be able to *understand* them.[24]

Moreover, in section 3.2 of this book, it was pointed out that not all kinds of visual representation are equally suitable for diverse communicative purposes. The background knowledge of the audience, the goal and the context of communication were highlighted as conditions essential to influencing the decision on how best to present the information. A similar case can be made with respect to the applicability of digital units. They might be useful in the context of information technology, but not as a basis for human epistemic processes. As such they have to be (re-)converted into a format cognitively accessible to human investigators.

The usefulness of digital information processing in epistemic practices is indubitable, but digital information itself should not be regarded as an *epistemically more basic* category of representing information. It is only a tool, a technology that works very well, the design of which, however, could also have been totally different. Nonetheless, we can infer the positive result that the possibility of digitalising images (as well as texts) shows that they contain information which can be extracted and decoded by using other representational means. Yet it might still be objected that the kind of information disclosed in its processing by digital devices is more or less trivial in nature. For example, it does not allow us to differentiate between images that are only used for decorative purposes and ones that are essential to the scientific argument. Thus, the focus of the question should be shifted slightly: are visual representations capable of bearing *meaningful information* instead of information in general (whereby 'meaningful' here refers to information relevant to the cogency of the arguments presented)? An instance of meaningfulness that plays a major role in this context regarding scientific images is the presentation of measurement data. As our example of the Higgs image (see Figure 2.4) has made clear, in many instances these measurement processes are connected to information-technology devices. This means that the results obtained can be presented by more or less all kinds of representational means. However, a translation between different modes of representation is also possible if no digital information is available. In many instances, there is, for example, the choice of presenting correlations between numerical data values in a table or visualised in a diagram. Accordingly, such visual representations can indeed be *bearers of essential information*, which was one presupposition for their possible role in scientific discourse.

Apart from this basic translatability, is there a kind of epistemic hierarchy involved when choosing between the different modes of data presentation? There are two points to be mentioned as a reply. Firstly, in section 2.1 of this book, it has already been shown that, depending on the context, some ways of presenting the data are more suitable to the task at hand than others. Secondly, such a task-orientated approach allows for the possibility that in some instances visual representations are epistemically superior to other kinds of representational means because they allow for an evaluation of data that otherwise would not be possible. Jutta Schickore offers an example in her discussion of a case study in astronomy (see Schickore 1999). Here, diagrams of a spectrographic analysis were used for the purpose of clarifying whether the data received showed two different interstellar objects or just one object, doubled by a gravitational lens (see ibid, ch. 3). Schickore points out that, in the end, it was a matter of a *qualitative visual evaluation* of the diagrams that guided the scientists in their decision. The *resemblance* between the two diagrams supported their judgement that only one object had been observed and not two different ones (see ibid., 282). It can be assumed that this judgement would not have been possible if the scientists had only the numerical data at their disposal.

In any case, it is not just resemblance and other relations between data that visual representations may easily reveal, but measurement errors can also be detected in this way. Sometimes the results have first to be depicted in a visual form before it can be decided what the real output is and what is just background noise. The Higgs image (see Figure 2.4) is a good example. One might argue that if inconsistencies or anomalies were detected, scientists would turn to the numerical database for clarification. This assumed procedure is then taken as supporting the claim that numerical data are epistemically more basic than their visual presentation. However, there are two points which call this reasoning into question. Firstly, scientists detect anomalies because they evaluate those very images and base their judgements on their own visual experiences with those representational means. That is, detecting anomalies would not be possible without visual representations. Secondly, not only does the epistemic process start with an image, but it also ends with one: the detection of an anomaly will surely result in the rendering of another image that can be used for comparative tasks. Thus, the whole process refers fundamentally to visual means. Of course, this line of reasoning should not be mistaken for claiming that processes of error detection and correction *always* work this way. However, it would be equally wrong to state that visual representations can in principle play only epistemically inferior roles.

Summarising the results so far, the analysis shows that numerical measurement data can be translated relatively easily into visual representations and vice versa. In addition it has been pointed out that there are particular tasks and contexts that make the use of certain representational means more reasonable than others. Consequently, there seems to be no fundamental hierarchy in place with respect to epistemic processes when comparing these two forms of information presentation. Despite this initial comparability between both means of representation, there is another way that might provoke claims of epistemic difference here, namely their usefulness in the context of scientific arguments.

In the previous section, it was highlighted that there are certain requirements that constitutive parts of arguments have to fulfil. They have to be bearers of truth values and they have to allow for certain entailment relations that make deductive reasoning possible. These characteristics are usually attributed to propositions. Moreover, it was stated that, despite there being rival conceptions of what is meant by the term ‘proposition’, one predominantly uncontested characteristic is that they are supposed to be *linguistically expressible*. Georges Roque gives the following synopsis of the dispute about visual representations in (scientific) argumentation that follows from accepting this condition of propositionality. “One underlying assumption is that arguments should be propositional. Consequently, if images are not propositional, therefore visual arguments are impossible unless the recipient extracts and builds propositions from them, which is a problematic process” (Roque 2015, 180).

Of course, the degree of the difficulty involved in translating the content of visual representations in a propositional way is greatly dependent on how we conceive of the concept of propositions itself. A more moderate stance towards this concept can be used to more or less circumvent the whole quarrel. J. Anthony Blair, for example, an early defender of the thesis that visual arguments are possible, chooses such a strategy. He claims that there is no particular problem related to translating visual content into propositions, as the latter can be expressed in a variety of different ways. He states that “[p]ropositions can be expressed in any number of ways, including silence […], but also by signs or signals […], or by facial or other body-language expressions […]” (Blair 1996, 26). As a consequence of this moderate conception of propositions, he infers that “[t]he visual expression of propositions, then, is familiar and relatively unproblematic” (ibid.). Whereas Roque argues that visual arguments are impossible as images are not propositional, Blair shifts the perspective by claiming that propositions can be expressed by very different means. That is, a claim about characteristics or essence is turned into a question about capacities of expressibility. This shift in perspective then makes it relatively easy for Blair to claim that “[…] visual arguments are not distinct in essence from verbal arguments. The argument is always a propositional entity, merely expressed differently in the two cases” (ibid., 38).

Roque, on the other hand, emphasises the relation between propositions and linguistic expressions, particularly when denying that images have the capacity to bear propositions. Thus, by mentioning the process of *extracting and creating propositions*, he refers to the question of the translatability of visual representations into linguistic expressions. This clearly more difficult approach to the topic can be obviated, however, by simply adopting Blair’s suggestion that propositions are in principle expressible in a diversity of ways, which would then render the task of translation redundant.

Perini’s approach attempts to deal with the persistent problem of the capacity to bear truth values. This becomes clear when Blair’s later works (see Blair 2004) are examined, for it is here that the objection based on the truth-bearing capacity of propositions is taken up in earnest. He offers two rejoinders to the objection that, as images cannot be bearers of truth values, they cannot express propositions (see ibid., 47). His first rejoinder is simply to offer an example of what he considers to be a paradigmatic case of a visual argument (see ibid., 47f.), namely a political, pre-World War II cartoon showing an Englishman sitting beneath a pile of boulders. These boulders are labelled with the names of European countries.

> The bottom boulder, sticking out but wedged under and holding up the rest, is marked 'Czecho'. […] A thick rope is attached to the out-thrust end of the 'Czecho' boulder and pulled up overhead and out of sight. Clearly a strong pull on that rope would dislodge the 'Czecho' boulder, causing the rest to come crashing down on the Englishman below. The cartoon's caption reads, 'What's Czechoslovakia to me anyway?'
>
> (Blair 2004, 48)

The message, i.e. the proposition expressed by this cartoon, is that the political fate of Czechoslovakia will indeed have a major impact on England. Moreover, Blair points out that this proposition was either true or false at the time of its publication (see ibid.).

His second rejoinder consists in highlighting that arguments are not only used to change the recipient's beliefs, but also her attitudes, intentions, or behaviour (see ibid., 48). These latter instances do not have truth values, as he points out (see ibid.). Apparently, this concession implies a softening of Blair's initial thesis. Yet it might be objected that, although Blair is right in claiming that "attitudes, intentions and conduct do not have truth value", this does not imply that argumentative attempts to change them do not rely on truth-bearing propositions. Blair's intention to ascribe a different important role to images in the context of argumentation by drawing on the psychological effects of visual means instead of their assumed epistemic contributions does not therefore undermine the thesis that they express a propositionally structured content.

Be that as it may, Blair concludes by pointing to the more moderate achievement that he thinks he has obtained, namely that his rejoinders to this objection "[…] at least […] shift the burden of proof" (ibid., 49). Alternatives have now to be contemplated, if his rejoinders do not convince, that create a way to keep visual representations nonetheless involved in the argument.

This brings us back to Roque's suggestion that although images cannot represent propositions themselves, their content can perhaps be translated into representational means capable of fulfilling this task. This comes down to questioning whether the content presented visually can be paraphrased, i.e. translated into linguistic expressions. Perhaps a mental reconstruction of arguments that is performed has to be taken into account of which the contemplating scholar is more or less unaware. But is the cognitive content of visual representations translatable into linguistic expressions in the way required for scientific arguments?

Blair thinks that, in principle, such a translation is possible (see Blair 1996, 25). Actually, he argues that visual representations pose no particular problem of translation. This optimistic attitude is a result of his more moderate conception of propositions. Yet he also seems to implicitly admit that there are limitations to the scope of such translations when he says that "[w]hether such descriptions or translations can be complete or fully adequate is a separate question" (ibid., 25). The difficulty has already been mentioned that, if visual representations are to be employed in communicative acts, certain limitations of expressibility have to be acknowledged. A related lack of image precision is highlighted in Elliott Sober's account. Similar to Blair, Sober starts in an optimistic way by expressing his conviction "[…] that every representational picture[25] has a sentential counterpart of a certain form which captures the content of the picture with which it is identified" (Sober 1976, 111). Consequently, Sober defends the thesis that a translation of visual representations is indeed possible.

Interestingly, his conception of how to translate visually presented information into linguistic expressions also allows him to explain in what sense images can be called true.

> A representational picture gives it to be understood that a certain state of affairs obtains. If a picture is *true*, then the state of affairs *does* obtain. For this reason, we will identify each representational picture with an existential hypothesis which posits the existence of certain specified objects. A picture will thus be true if and only if the world contains the kinds of objects demanded by the sentential counterpart. True pictures are thus ones that have *verifying instances.*
>
> (Sober 1976, 111f., his italics)

Sober's suggestion is much more precise than the proposal made by Tim Crane, who discusses the question of whether images can have a propositional content (see Crane 2009). He assumes that "[f]or any picture P, there is a sentence which gives the content of P" (ibid., 460). At first glance, this seems to be quite similar to Sober's approach. However, Crane thinks of the sentential counterpart of images as mere descriptions of their contents, not as an "existential hypothesis which posits the existence of certain specified objects" (Sober 1976, 112), as Sober does. Crane uses this line of reasoning to conclude that there is still an important difference between the image's content and its description (see Crane 2009, 460). He infers from this that such sentential counterparts to the content of pictures do not support the thesis that images have propositional contents (see ibid., 461). Obviously, this reasoning is a consequence of Crane's identification of "a sentence which gives the content of P" with "a description of P" which allows the latter to be rather loosely connected to the visually encoded information. Here, Sober's thesis is much more precise in pointing out that the sentential counterpart has to entail an existential hypothesis of a certain kind. From my point of view, this precision is ample reason for preferring Sober's account to Crane's approach.

Yet this preference does not imply that Sober's approach presents no difficulties. Whereas the idea that there is a kind of test to check whether images that are supposed to represent certain entities of the world fulfil their task successfully seems to be more or less uncontroversial, the moot point in this conception is, of course, Sober's claim that it is the picture and not the correlated sentence that is true. Suggesting such a way of evaluating the content of visual representations apparently calls for precision when it comes to the task of translating its content. If we want to check whether a particular state of affairs that a certain picture shows actually obtained, as Sober puts it, we not only need a vague description of what is going on in the picture, as Crane e.g. suggests, but a precise translation. And although Sober's account is preferable to Crane's, as the former makes clear what kind of description is called for, for two reasons Sober's approach unfortunately does not fulfil requirements either. Firstly, there is Sober's own discussion of the limits to what is visually expressible. Secondly, there is his concession that analogue pictures cannot be completely translated in the way suggested above (see Sober 1976, 141).

Concerning the first aspect, Sober points out that visual representations lack the capacity to express negations[26] and disjunctions. With regard to the former, he notes that:

> […] the absence of negation has two parts: On the one hand there is no operation on a picture that produces a picture whose interpretation is the negation of that of the one operated upon. On the other, predicates occu[r]ring in the interpretation of any representational picture are such that their negations never so occur.
>
> (Sober 1976, 128)

Adhering to his idea of translatability, he points out that there is no logical way to produce two images whose sentential counterparts are contradictory, and consequently he claims that there is no such thing as pictorial negation.

One might object that there are, for example, drawings in field guides for biologists that show a particular characteristic that dragonflies, say, belonging to the species *Emperor* always show a black mid-line stripe on the abdomen. Of course it is possible that this characteristic is omitted in another drawing. But although in such a case there is a picture showing p (black stripe), and the other one does not *not show p*, i.e. an example of an Emperor without a black stripe, this is not a negation of the former image but simply an image of a different species.

Sober presents a similar argument concerning the possibility of disjunctive claims via visual representations. "There is no operation on pairs of pictures which effects their disjunction, and if two predicates occur in an interpretation, their disjunction never so occurs" (ibid.). No doubt, there is a broad variety of different pictures, but how could a relation between two of them be produced to express an alternative to what is shown?

Although Sober has highlighted serious shortcomings of visual representations as means of scientific communication, he does not regard this as proving the impossibility of translations between images and verbal expressions. On the one hand, he does not defend the thesis that a presumed translatability works both ways – from the visual to the linguistic and vice versa. He only emphasises that the first route – from visual to linguistic representations – is always possible in the case of representational images.

On the other, he circumvents the problem by diminishing the relevance of those logical relations, discussed above, in human sense perception: human vision is developed by evolution to allow for a well-informed orientation in our natural environment. "For this reason, it [human perception, N.M.] is supposed to pick out properties of the environment that are significant in terms of prediction and explanation" (ibid., 131). Sober thinks that it is only natural properties that can fulfil the relevant task. Consequently, he claims that human vision is adapted to perceiving predominantly natural properties. He transfers this line of reasoning via an analogy to picture perception. By claiming that the basic cognitive processes in both instances are quite similar, he takes it that "[h]ence one should expect pictorial interpretations to fail to include irreducible disjunctions and negations, since these fail to pick out properties" (ibid., 131). What Sober apparently hints at is that, as we decode images via perception, the presentation of visual information has to obey the same limitations (or environmental accommodations, to put it in a positive way) as everyday perception does. In short, if we do not observe negations in the world, it should come as no surprise that they do not belong to the repertoire of what is expressible via visual representations.

Of course, this is quite a controversial claim that Sober inserts into his argumentation at this point. Although he might be right that human sense perception is particularly adapted to noticing certain entities in the world better than others, this does not constitute a reason that the expressibility of pictorial representation should be limited. Why should images not be able to present information that we usually do not perceive in our natural environment? Why should it not be possible to learn with this respect? Many scientific visualisations probably exhibit phenomena unfamiliar to everyday perception: the Higgs image (see Figure 2.4), for example.

Anyway, what should have become clear is that there are certain relational properties, such as negations, that cannot be expressed via visual representations.[27] Now, for the initial concern about questions of translatability from one representational mode into another, this means that there are certain constraints on transferring information *from the linguistic to the visual domain*. Although this does not pose a problem for Sober's own thesis that all representational images can be translated into linguistic expressions, a difficulty arises that does affect his project, namely translations *from the visual to the linguistic domain*. Here, complications arise when we want to translate what he calls *analogue pictures*.

What are analogue pictures in Sober's sense?

> In saying that a representational system is analog, we are claiming that there is a property of representations which the system treats as significant, and which is such that if there were a continuum of values of the property, there would be a continuum of significantly different representations.
>
> (Sober 1976, 139)

Because of these possible continua of property values, an analogue system of representation is usually richer than a digital one regarding the information it presents. Although translation into a digital system – such as natural languages – is possible, it implies a loss of information and, thus, "a loss in precision", as Sober points out (ibid., 140). A translation of the content of analogue pictures into linguistic expressions can therefore be achieved only approximately, that is, with a considerable lack of precision (see ibid., 141). This lack of precision is the result of there being a number of very different possible sentences derivable from an analogue picture via translation, which also limits Sober's initial thesis that the truth of pictures can be proven via verifying instances expressed in the sentential counterparts of images. If there is a variety of different sentential counterparts, no definite verifying instances can be stated.

To sum this up, Sober's account of the relation between linguistically and visually presented information seems to be correct. We are obviously able to describe what we see in representational images to a certain degree, and can thus take this as supporting the thesis that *there is* a cognitive content of visual representations that can be used to transmit certain information. Moreover, the discussion of Sober's ideas also makes plain that there are certain limitations to what is expressible in the visual format, but also highlights the fact that these limitations hold vice versa, i.e. that the informativeness of the visual content can outstrip the capacity to represent information in linguistic expressions. As a result, *a reduction* of visual information to the latter *is not possible*. Or, as Sober puts it:

> [h]ence, not all pictorial systems are reducible to impoverished linguistic systems of a certain kind. The relation of analog pictorial systems to language is more complicated: With respect to logical operations on representations, linguistic systems are more powerful, but with respect to expressing specifically visual relations between posited objects, linguistic systems can be more impoverished.
>
> (Sober 1976, 139)

It might be objected that images not only contain more information, but also raise the issue of ambiguity by this. Hence their richness of information might turn out as a particular shortcoming, especially in the context of scientific arguments. The soundness and validity of an argument depend on the precision of its premises and its conclusion. If visual representations cannot guarantee this, they might be inappropriate as representational means in this context.

A rejoinder to this objection has been worked out by Blair. He highlights several aspects diminishing the sceptical attitude towards visual representations in scientific arguments (see Blair 2004, 46f.). Blair states that ambiguity and vagueness are not attributes exclusively attached to the visual domain, but also to linguistic expressions. Nonetheless, difficulties of understanding are mostly ruled out by information provided by the context of uttering an argument. Moreover, visual arguments are usually mixtures of verbal and visual representations so that the former can (and are) used to disambiguate the latter.

This fits neatly with what was stated earlier about taking the whole communicative act into account when considering the meaning of particular visual representations. It is advisable here to follow Kjørup's account of the topic. Similar to Blair's idea, Kjørup points out that the context and the combination of visual and linguistic expressions will enhance our understanding of visually transmitted information, as the former will help to disambiguate the latter. Thus, we can conclude that ambiguity and vagueness pose no particular problems with respect to visual arguments.

What would be more interesting to know is whether the comprehensive informativeness of visual representations, pointed out by Sober and others, also entails *information that in principle cannot be transmitted by other representational means*. If this were the case, not only would the quantity of information of certain images be different from other representational means, but also their quality, i.e. the kind of information that can be transmitted via visual representations, would differ.

Taking a look at concrete examples suggests that this might indeed be the case. For instance, Perini discusses the question of whether a micrograph can be translated into linguistic expressions. Pointing to the same continuum of property values that Sober highlighted above, she comes to the conclusion that a reduction to verbal language is not possible. She offers the following reason as a rationale for her inference:

> [b]ecause the form of pictorial symbols is correlated exactly with features of their referents, a dense range of extremely complicated properties can be expressed by a pictorial system. This kind of system is extremely useful in science because it allows for the representation of properties, whether or not the vocabulary exists to refer to those properties with linguistic representations. As a result, a verbal description of the shape of the figure will convey less specific information about the shape of the sample than the figure itself.
>
> (Perini 2005c, 923)

Here, she highlights the fact that visual representations can transmit information that have no linguistic counterpart, i.e. no linguistic expressions available to adequately describe, let alone translate, what is occurring in the image. It is this characteristic feature of visual representations, namely that they enable communication about entities and states of affairs without the appropriate words available for them, which makes them particularly useful in scientific arguments (see Perini 2010, 144).

However, if we take it that propositions are connected to linguistic expressions, at least in the sense of being expressible by them, then Perini's example suggests the interesting conclusion that some scientific images can transmit *non-propositional content*. Moreover, if images contain such a kind of cognitive content, then the strategy of translating their content in order to adhere to the traditional conception of proposition-based arguments will be blocked. It is also this line of reasoning that motivates Blair's claim that "[f]or visual argument to represent a radically different kind of argument, it would have to be non-propositional" (Blair 1996, 34).

Moreover, as Perini's example makes clear, it would be wrong to dismiss visual representations as devoid of substantial information. On the contrary, they can contribute a kind of information that apparently cannot be transferred by linguistic means. Yet how is this information perceived, how is it cognitively processed so that it can play a role even in scientific arguments, and can knowledge be acquired in this way if the latter is usually considered to be propositional in kind?

Obviously the main process of cognitively accessing the content of visual representations is by visual perception. Thus, the next question to answer must therefore concern how perception is connected to propositional content or to non-propositional content respectively. Analysing these relations will offer an explanation of the possibility that the non-propositional content of images can play a role in scientific arguments.

4.2.2 Perception and non-propositional content

This section will be concerned with the nature of the content of perception. In particular, the question will be discussed whether this content is propositionally structured. The answer to this question will facilitate greater precision about the kind of content perceivable when regarding scientific images. Two aspects of the following line of reasoning are to be highlighted at this initial stage: firstly, it is particularly the theoretical assumptions put forward by Christopher Peacocke that will afford a connection between the debates in the philosophy of perception and in picture theory. Secondly, although the main focus of the analysis is on perception as an epistemic source, it will turn out that the interplay between different sources of knowledge is of relevant consideration in order to explain sufficiently what kinds of content can be transmitted in image perception as well as in perception in general.

Philosophical considerations of perception are related to different branches of this academic discipline. There are phenomenological approaches as well as epistemological ones, but the topic is also connected to questions of the philosophy of mind.[28] Regarding the current topic, two constraints need mentioning that will restrict the set of theoretical approaches that have to be taken into account: epistemological questions on the one hand and the cognitive mechanisms of vision on the other – although other sense modalities might play a role as well. In the following, only those parts of the debate about perceptual knowledge that are closely related to epistemological questions of picture perception in science will be examined.

It is not usually called into question that knowledge ascriptions are made, and are also often justifiably allowed to be made, based on the *epistemic source* of perception. It seems to be perfectly admissible to reply "Because I saw *that p*" to the question "How do you know *that p*?". This becomes particularly apparent when considering the debate about knowledge by testimony. Here, perception is commonly regarded as a more or less uncontroversial exemplar of an epistemic source, whereas philosophers still dispute whether testimony can have parity with perception in this respect. Participants of this debate seemingly have no qualms about regarding perception as an *epistemic source*. What is meant, then, when *sources of knowledge* are discussed?[29]

Robert Audi specifies the epistemic achievements of those sources in the following way:

> [a]s I am understanding sources of *knowledge*, and as they are generally conceived in philosophical literature, they are not just where knowledge comes from; they also provide the knower with grounds of knowledge. Grounds are what it is in virtue of which (roughly, on the basis of which) one knows or justifiedly believes. […] sources indicate the kinds of grounds to expect a person to have when a person has knowledge through that source.
>
> (Audi 2002, 82, his italics)

Thus, epistemic sources not only tell us how certain beliefs are acquired, i.e. which cognitive resources are used in in this process, but also yield reasons that can justify the corresponding beliefs. Mentioning an epistemic source as a reply to the question "How do you know *that p*?" is commonly regarded as a *prima facie justification* of the corresponding belief. Hence, from an internalist's point of view, epistemic sources differ from mere causes of beliefs in that they provide us with reasons to think that the belief acquired is true, as Thomas Grundmann points out (see Grundmann 2008, 453). From an externalist's point of view, epistemic sources specify *reliable ways (or methods)* of belief formation. Of course, these cognitive processes are not infallible, but philosophers acknowledge them as usually leading to true beliefs. They also agree that epistemic sources *can* yield knowledge, i.e. *propositional knowledge*. Grundmann makes clear that calling x an epistemic source implies a positive epistemic evaluation of x. Making use of x in one's cognitive processes will usually imply that one will gain knowledge from x (see ibid., 455).

Perception is usually regarded as belonging to this set of epistemically distinguished sources. In the debate about knowledge by testimony, perception is even regarded as a *paradigmatic example* of such a source. Acknowledging this means accepting that perception enables epistemic subjects to gain propositional knowledge.[30]

Despite the agreement of many philosophers on this positive epistemic assessment of perception, and also their acknowledgement of the thesis that it is propositional knowledge that is at stake when contemplating the achievements of epistemic sources in epistemology, there is no consensus on the nature of perceptual content (see e.g. Siegel 2015). A primary consideration here is whether this content is propositional or non-propositional in kind. A propositional content would provide accuracy conditions with respect to claims concerning what has been perceived by a particular speaker (see ibid., sect. 2). As was pointed out above, considered in the Fregean tradition, a proposition is commonly regarded as an abstract object which is either true or false. Scholars also agree that propositions can be expressed by linguistic statements. Beyond this, however, there are also *concepts* that are related to both propositions and to language.[31] Now, some think of concepts as the "constituents of propositions" (Margolis and Laurence 2014, sect. 1.3). Regarded this way, the question of whether the contents of perceptions are propositional or non-propositional in kind also implies the question of whether their contents are conceptual or non-conceptual. Saying that those contents are propositional would then also mean to claim that they are conceptual, and, following Frege, these contents can then be expressed by verbal statements.

However, the precise relation between concepts and propositions is far from clear and the discussion about the contents of perception therefore becomes even more complex when taking this relational aspect into account. Grundmann, for example, questions the cognitive process involved in perceptual activities in this respect. He wonders how perceptual content is turned into propositional knowledge if perception transmits non-conceptual contents, an assumption which he defends (see Grundmann 2008, ch. 7.1.2). As a rationale for his thesis that the content of perception is non-conceptual in kind, Grundmann states, amongst other things, that we are able to perceive entities, for instance, different hues of a colour, for which we have no concepts (see ibid., 492).[32]

In particular, philosophers ask how sense experience and perceptual beliefs are related. Perceptual beliefs are regarded as propositional attitudes here. From a Fregean point of view, fulfilling their task as accuracy conditions also implies being expressible by verbal statements, which seems to presuppose that those contents are conceptualised. Grundmann makes clear that we should not simply identify perceptual content and perceptual beliefs (see ibid., 488f.). In particular, cases of optical illusions show that sense perceptions are quite robust even when challenged by background knowledge. That is, although the epistemic subject is aware of being misled by her perceptual apparatus, because she knows how the optical illusion at hand works, she is not able to change her perceptual experience. Consequently, she will have a particular visual impression, but will not believe what she sees because she knows about the illusionistic mechanism at work. Interrupting the process of belief formation in such a way, however, seems to be rather exceptional because we do not usually question what our senses tell us about the world but just believe what we perceive. More often than not, perceptual experiences are then turned into perceptual beliefs. For the moment, the answer to Grundmann's question about how exactly this process of transformation works will be left open. It will be explained below when we consider Peacocke's theory of non-conceptual perceptual content. What is of importance to the current investigation, however, is noticing the fact that this process usually works reliably. That is, perceptual contents are turned into perceptual beliefs, even though the former can be non-conceptual in kind, whereas the latter are commonly regarded as propositional attitudes that presuppose a conceptualised content.

In the context of science, Hentschel offers an illustrating example of observations that yield non-conceptual content and of scientists' subsequent attempts to conceptualise what they have observed. He describes the first observations of the surface of the sun in the nineteenth century (see Hentschel 2000, 23ff.). The solar structures, now known as granulation, visible with contemporary telescopes, were completely unknown to astronomers of that time. Thus, they not only lacked the words to describe what they had observed, but also had no conceptual background knowledge about the mechanism producing this phenomenon. As a strategy to circumvent the descriptive problem, astronomers made use of different metaphors, e.g. "willow leaves in an ocean of fire", "rice grains", etc. (ibid., 23) to report their observational results. Moreover, these metaphors were also used to pictorially illustrate their observations in their publications. Here, Hentschel points out that those images were particularly important to subsequent research activities about the related phenomenon, as they influenced significantly the way scientists observed it later on:

> [w]hat is at issue here is far more than terminology: Behind these competing 'descriptive labels' are mutually exclusive options on how best to see a new feature, that is, which Gestalt is assimilated to their visual impressions. […] And these published illustrations in turn strongly influenced the perception of other observers […] about what they anticipated seeing, that is, recognizing, in their telescopes.
>
> (Hentschel 2000, 23ff.)

By making use of metaphors (linguistically and visually), those scientists started conceptualising the phenomenon of granulation that they were observing. Those metaphors allowed them to refine their observations by offering a point of comparison to already-known phenomena, to exchange ideas about their observational results and, later, to develop hypotheses to explain the mechanism in the background. This example makes plain that human observers are apparently able to receive perceptual information, although they lack the concepts to explain and to describe in concrete terms what they have seen.

Here we find an explanation for why it is possible that some scientific images can transmit information we cannot describe by using linguistic expressions as we do not have the relevant words to do so – i.e. the thesis defended by Perini above. On the one hand, images can be used to transmit information about phenomena during the process of their conceptualisation, as Hentschel's example demonstrates, and, on the other, scientific images – in particular those working in a causal way, i.e. that are causally related to the object under investigation – can also contain non-conceptual information about the entity they represent; and, as it is through perception that we grasp such non-conceptual information, so human observers can learn about those entities by regarding the respective images.

Philosophical analyses of perceptual content also allow us to learn what *non-conceptual contents* might be like. Postulating such a kind of content is the result of acknowledging the above-mentioned thesis that the content of perceptual experiences and corresponding beliefs are not identical. Susanna Siegel calls a corresponding thesis of identity which explicitly refers to concepts in this context "experience conceptualism" and defines it as follows: "[f]or any object *x* and any property *F*, a subject has an experience as of *x* being *F* only if she has concepts of *x* and *F*, and deploys those concepts in the experience" (Siegel 2015, sect. 6). The relation between beliefs and experiences expressed in this statement can be grasped more quickly by identifying the contents of beliefs with the contents of experience. Siegel calls this the "same-content" thesis: "[f]or any experience as of an object *x* having a property *F*, if the experience has content *p*, then it is possible to have a belief with content *p*" (ibid).

Both of these theses are challenged by the fact that perceptual experiences can apparently be informatively richer than the concepts people are able to deploy, as Siegel points out (see ibid., sect. 6.1). Consequently, it can be argued that if non-conceptual information is acquired via perception, then (at least) some perceptual contents are not bound to concepts in the first place. The example of the first observations of the granulation of the solar surface illustrates this point nicely. Scientists at that time had no concept of the phenomenon at their disposal. That is, they could neither verbally describe what they had observed nor explain what was occurring, namely what caused the phenomenon they were observing, what mechanisms were responsible for causing it, nor why it looked the way it did. Nonetheless, they were able to see those particular structural aspects of the solar surface.

A first approximation to the concept of 'non-conceptual content', then, consists in acknowledging the fact that we are dealing with a contrastive concept here, as José Bermúdez and Arnon Cahen point out (see Bermúdez and Cahen 2015, sect. 2). That is, our understanding of the term 'non-conceptual content' depends crucially on how we conceive of the term 'conceptual content'. Consequently, there is a variety of hypotheses available about what exactly the non-conceptual content of perception might be like.

The contrastive nature of the term 'non-conceptual content' is also highlighted by Christopher Peacocke (see Peacocke 2001a, 243). He briefly addresses the relation assumed between concepts and language in his discussion of this topic.

> If someone holds that a concept user must have a language in which he can express at least some of his concepts, that is a substantive, nondefinitional thesis that needs to be established. […] It should, however, be uncontroversial that any content that can be expressed in language by the use of an indicative sentence, including sentences containing indexicals and demonstratives, will be a conceptual content.
>
> (Peacocke 2001a, 243)

Thus, having concepts at one's disposal does not necessarily urge us to admit that we possess a language to express those concepts. Consequently, the inability to speak, either temporarily or permanently, is no necessary indication that the corresponding person does not have concepts at her disposal. It is only the weaker thesis, namely that what has already been formulated in language is automatically related to concepts, that Peacocke holds to be uncontroversial when considering the question in what sense concepts and language are related to each other. Thus, Peacocke's ideas caution against claiming too close a relation between language and concepts.

Can the nature of non-conceptual content of perception be described in a more substantial way? Here, Peacocke's approach is particularly interesting, as his considerations bridge the gap between the discussions in the philosophy of perception and in picture theory. With respect to the latter, he thinks that philosophers should take into account results from cognitive science, in particular from theories of perception (see Peacocke 1987, 383, 404). In the following summary, together with a discussion of some related examples, a recapitulation of what he suggests in the context of his theory of depiction will help to clarify why the transmission of non-conceptual content is important in epistemological terms and what kinds of cognitive processes are at work.

As was explained in section 2.2.1 of this book, Peacocke uses the concept of the "visual field", borrowed from theories of perceptual experience, to elucidate where exactly to look for resemblance relations between an object and its depiction. According to this assumption, it is not the direct properties of an object and its depiction that are compared, but properties belonging to the perception of image and object. That is, what is compared are experiences of the object and of the image in the visual field of the perceiver. The visual field can be regarded as a kind of mental intermediate plain between perceiver and the object of perception. It is then in experiences of the image and the object in this visual field that resemblance relations are detected (see ibid., 386). Now, if the perceiver possesses the relevant concept to identify and label the object correctly, i.e. if she makes use of this concept as a comparative instance to her experience of the image at hand, Peacocke suggests that what is presented to the perceiver in the visual field is then "F-related" ('F' refers to 'field') to that very concept (see ibid., 387). The Altamira cave painting is a good example (see Figure 1.1). According to Peacocke, the viewer will experience a particular similarity in the shape of the painted animal and of a living example of the same species in her visual field. Moreover, if the viewer possesses the concept of an aurochs, she can cognitively proceed by calling the cave painting *an image of an aurochs*.

But what happens if the corresponding concept is not available to the viewer? Here, Peacocke brings in the idea of a non-conceptual content in his theory of depiction. He argues that there are images – most of all, abstract paintings – that are experienced as having representational qualities,[33] that is, they will be experienced as showing particular shapes, although the viewer does not possess the concepts that would allow her to describe her visual field experience linguistically. Moreover, Peacocke thinks that the content of the viewer's experiences can nonetheless be "assessed as veridical or non-veridical" (ibid., 395).

To explain why it is that the viewer's experiences of the respective image represent the latter as showing certain shapes, although the relevant concepts are not available, Peacocke brings in what he calls the "analogue content" of pictures (see ibid.), which he considers to be non-conceptual in kind. Moreover, he is convinced that assuming the possibility of such a kind of content being transmitted in at least some processes of picture perception is crucial as:

> […] it explains how there is room in the space of logical possibilities for something that actually occurs: the acquisition of a recognitional capacity for a kind of object (or an individual) by seeing a depiction of a member of that kind (or of that individual).
>
> (Peacocke 1987, 395)

An illustrative example of this is provided by images in field guides for biologists. Consider the following case: I observe a particular bird of prey circling Lake Geneva. As I do not know what this species is called, I want to identify it with the aid of a bird guide. Before consulting this book, all I know about the animal is that it is a bird of prey hunting for fish and has a certain appearance during its flight, that is, I know how its tail is formed, perhaps its colour, and I have a rough estimation of its size. So, my observation and my interest in the species have already triggered my attempt to conceptualise my observation. Nonetheless I still will not be able to classify the bird with the aid of a verbal description, as there are too many uncertainties correlated with my brief observation. The bird guide, however, provides a series of drawings of flying birds of prey that I can use as a means of comparison. That is, I can now compare these pictures with my mental image, derived from my memory, of what the bird looked like during its flight. Obviously, what finally makes a classification possible is this comparative task when considering similarities and dissimilarities between the appearance of the bird that I remember and the respective image printed in the book. Hence, although resemblance relations might not be the *non plus ultra* explanation of the phenomenon of depiction in general, they nevertheless prove to be an important aspect in our handling of images. In particular, they help us to conceptualise a phenomenon by using images as teaching tools. What is made plain by this example is that, like perception in general, picture perception can transmit non-conceptual contents, for example about similarities and dissimilarities between an object observed and a drawing in a field guide. They can contribute to our acquisition of concepts and be turned into linguistically expressible beliefs later on. Therefore, Peacocke's concept of "analogue content" connects picture perception with our broader visual capabilities.

Peacocke suggests a similar line of reasoning. He thinks that, in general, images can help us to recognise later on what they depict. That is, by showing you an image of a flying swift,[34] you will be able to discern one in the wild. You will know, for example, how to distinguish a flying swift from a flying swallow, although you have not had the relevant concepts to explain and describe this difference beforehand. In this sense, images can contribute to the conceptualisation of phenomena. It is the non-conceptual content of perception that explains how we are able to acquire observational concepts in the first place (see Peacocke 2001a, 252ff.). That we finally possess the relevant concept is indicated by our ability to correctly recognise the respective entity afterwards.

This, then, is how analogue content works and why it is important. But what exactly does it consist of? Siegel claims that non-conceptual content in Peacocke's sense can be subdivided into "scenario content" and "proto-propositional content" (Siegel 2015, sect. 6.2). For both of them, it is essential to note that Peacocke distinguishes clearly between the properties of the content of an experience and the properties of an object, or event, that is perceived. These properties can show relevant similarities, but need not do so.

An example of this phenomenon concerns distorted experiences. That is, perceiving an entity x from an oblique angle – or from a non-optimal point of view – will present x with a distorted shape in our experience. Its shape might, for instance, appear squeezed or stretched – although x's actual properties of shape have not been altered in any way.[35]

The content of experience can thus diverge from what has been perceived by the viewer. There is an additional dimension, so to speak, entailed in the content of our experience, namely *the way we perceive* those entities.

> So, in characterizing the fine-grained content of experience, we need the notion of experience representing things or events or places or times, given in a certain way, as having certain properties or as standing in certain relations, also as given in a certain way. Henceforth, I use the phrase *the content of experience* to cover not only which objects, properties, and relations are perceived, but also the ways in which they are perceived.
>
> (Peacocke 2001a, 241, his italics)

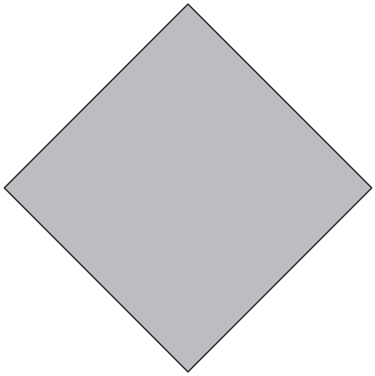

Figure 4.4 Non-conceptual content of perception: the same shape can be experienced either as a regular diamond or a square.

Source: own image.

To illustrate what kind of information is added when our perceptual content contains the ways we perceive things, Peacocke discusses an example presented by Ernst Mach. According to Mach, Figure 4.4 can be perceived either as a regular diamond or as a square, without the actual properties of the figure being altered. Consequently, the way that we perceive the figure is either as a regular diamond or a square. This information is added to our content of experience of Figure 4.4, although the properties are not changed.

Now, although the content of our experience and what has been perceived by us can diverge in the way just explained, the latter is nonetheless the cause of the former (see Peacocke 2001a, 248). This is also why Peacocke thinks that the content of our experience can indeed be assessed with respect to its correctness (see ibid., 240f.) which implies that we cannot just make up our minds. What can be perceived is restricted by this causal connection between the entity and our content of its experience.

Within this framework, Peacocke highlights two different kinds of non-conceptual content of experience. The first one is what Siegel calls "scenario content". She explains that "[s]cenario content is a set of ways filling out the space around the perceiver, relative to an origin and axes marking directions, that is consistent with the perceiver's experience being veridical" (Siegel 2015, sect. 6.2). Or in Peacocke's words: "[s]cenario content is essentially the notion of a spatial type, a type an experience can represent as instantiated in the volume of space around the subject of the experience" (Peacocke 1994, 420). Thus, the scenario content is related to the location of the perceiver in her environment during a concrete perceptual episode. Usually the scenario content of an observer is related to her conceptual states. Yet this does not imply that the scenario content itself is (completely) conceptualised (see ibid., 422). Think, for example, of the concepts of being left or right. Apparently we are able to experience a cat crossing our path from the left to the right although we might not possess the concepts of 'left' and 'right'. We would not say that, before acquiring them in our childhood, we were not able to entertain the relevant experience.

The second kind of non-conceptual content is called *proto-propositional content*. This type of experiential content is needed as there are instances when the scenario content of a perceptual experience remains the same, although these experiences differ phenomenally (see Siegel 2015, sect. 6.2). An example that Peacocke discusses with this respect is Figure 4.4. Although both the shape and the scenario content remain the same, this figure can be regarded either as a square or as a regular diamond. What changes is "the way in which some property of relation is given in the experience" (Peacocke 2001a, 240). Yet, despite this last explanation, it remains difficult to understand what kind of information is added by this way of givenness in the perceiver's experience. Apparently it is not about the perceptual setting – i.e. directions, relations, lighting conditions, etc.– as this is what the scenario content is supposed to transmit.

Nonetheless, the ways things are given in our experience are essential, as Peacocke makes plain, because they provide the foundation to conceptualise what we have perceived. He points out that concepts presuppose some kind of raw material or information, so to speak, from which they can be formed. Thus, the non-conceptual content of our experience precedes the process of conceptualisation (see ibid., 245f.). Moreover, those ways of givenness in experience correspond to certain kinds. "On reflection, it should not be a surprise that for each way, there is a specific kind such that the way is intrinsically a way for something of that kind to be perceived" (ibid., 246). Concerning Figure 4.4, this means for example that the way this figure is given in our experience can correspond either to the perception of a square or a regular diamond, but not to the perception of a circle. Experiencing the figure as having four edges is the condition that allows us to subsume it in a certain category and this way of experiencing Figure 4.4 excludes it from belonging to the set of phenomena that can be called a circle. It is the way Figure 4.4 is given in our experience that allows us to judge that this is a square if we do possess the concept of squareness, i.e. if we know that a condition of being a square is 'having four edges' (see ibid., 253). This is why the way of givenness in our experience is proto-propositional. It is the foundation for respective judgements which allow us to formulate corresponding that-clauses, but it is not conceptualised as such.

Peacocke explains what is going on in such instances when discussing how the transition from non-conceptual content to observational concepts is achieved. He suggests that perceivers:

> […] will be displaying a sensitivity to a particular boundary. This is the boundary between those states which are, and those states which are not, mentioned in the possession condition for a given concept such as *square*.

> […] One, perhaps the basic, way to make this transition is to ask questions that are in the first instance not about concepts, but about the world. […] One can answer such questions by drawing on one's ordinary, ground-level abilities to react rationally to one's perceptual states in coming to make judgements about the world.
>
> (Peacocke 2001a, 258)

Thus, the thesis is that we do need the non-conceptual content of experience to acquire the concepts that allow us to make judgements about the world, to describe and communicate about it.

Here, we can add an important point related to this nexus between the non-conceptual content of experience and the acquisition of concepts. Peacocke points out very clearly that it is because of this kind of *content* that this latter cognitive achievement can be accomplished. He thereby rules out an important rival to his theoretical approach, namely discussing *states of perception* instead of *contents of perception* in this debate. Tim Crane suggests that Peacocke's theory of scenario contents can be used also as a rationale to defend such a state-orientated view of perceptual experience.

> Peacocke's theory might seem to be a version of the content view, but properly understood, it is a version of the state view. The reason why a state with scenario content is non-conceptual is because S is not required to possess any of the concepts that canonically characterize the scenario in order for S's state to be canonically characterized in terms of it.
>
> (Crane 2009, 468)

Peacocke, however, highlights the possibility of making transitions from non-conceptual to conceptual contents of experience. Apparently this is what we experience in the processes of learning, and it seems to be much more plausible to assume that our concepts are formed – or carved out – of a *raw content*, namely a non-conceptual content, than that they appear because of their relation to a non-conceptual state.

In the following, we will discuss some clarifying remarks that will bolster Peacocke's claim concerning how to conceive of the cognitive process of concept acquisition. Two supplementing ideas referring to human developmental history are worth considering here. Those ideas will shed some light on what Peacocke might have had in mind when writing about proto-propositional content.

Firstly, it can be assumed that our perceptual apparatus has been crucially shaped by evolutionary processes. That is, only those of our species survived who were able to react reasonably adequately to what they had perceived. Forming proto-propositional contents about one's environment, about food, predators, members of and threats to one's community apparently seem to have been evolutionally advantageous. Such a line of reasoning appears to lie at the heart of Peacocke's thesis that human beings are sensitive to certain boundaries concerning the conditions of the possession of concepts.

Secondly, as mankind has always been a social species, it is strongly advisable to take into account that the process of learning has not to be mastered by the individual alone. On the contrary, we can, and usually do, rely on members of the family, relatives and other human beings in general. That is, we rely on the division of epistemic labour. Thus, it is rational to assume that not only perception and testimony often work hand in hand as epistemic sources when it comes to language acquisition (see Bermúdez and Cahen 2015, sect. 4.1), but that they also co-operate when we learn about concepts in the broader sense. Parents show their children the entity they name for them (see Harris 2012, 8). By repeating this show-and-tell event and by the children's listening to subsequent parental explanations about what is characteristic of those entities, children will come to be aware of the boundaries of certain concepts and, later, will know how to deploy them in language. Requiring that concepts always come first would apparently undermine the whole cognitive process just described.

However, it would be equally wrong to deny that the ability to deploy concepts can contribute much to what we are able to *observe*, as Chalmers has highlighted (see Chalmers 1999, 10ff.). His concern is that observational facts have to be formulated as statements to be of use in scientific reasoning – a claim that reminds us strongly of the controversy about the role of images in scientific discourse. As a result of this assumption, Chalmers thinks that we are in need of an "appropriate conceptual framework and a knowledge of how to appropriately apply it" (ibid., 11) to formulate those sentences. Moreover, he shows that the better – i.e. the more appropriate to the task at hand – our observational concepts are, the more detailed our scientific observations can become.

This interplay between concepts and observation also appears in Hentschel's example of the first observations of the solar surface. Not only does he demonstrate the difficulties that those first observers had to face in trying to understand the visual information their telescopes conveyed to them, he also explains how their strategy of analogical reasoning, i.e. the application of metaphors to describe their observational results, influenced later observations of the respective phenomenon. Hentschel describes this process as a search for and application of different *Gestalt concepts* (see Hentschel 2000, 23). Moreover, he notes that published illustrations influenced what other scientists expected to see and actually observed (see ibid., 25). We have already become acquainted with what Hentschel describes here through Fleck's ideas about scientific communication processes and the place of visual representations therein (see section 3.2.3 of this book).

Fleck makes plain that often there is a feedback loop between popular science and expert knowledge (see Fleck 1979, 115ff.). In particular, he shows how images, produced as means to communicate results in a simplified manner to laypeople, influence the experts' cognitive processes. "But what was initially meant as a means to an end acquires the role of a cognitive end. The image prevails over the specific proofs and often returns to the expert in this new role" (ibid., 117). Thus, to use Hentschel's terminology, once a concrete pictorial *gestalt* – putatively formed by deploying certain concepts – has been chosen by the expert to present her results, this *gestalt* will determine what she will henceforth observe and investigate.

Moreover, the above discussion of the non-conceptual content of perception allows us to explain why this initial choice of a pictorial or descriptive *gestalt* does not lead into an epistemic dead end and, thus, to a cognitive standstill if those choices are not adequate. Fleck describes what might have been expected, namely a particular tenacity of thought styles and what he calls a "harmony of illusion", i.e. the tendency to explain phenomena in accordance with the prevalent thought style or even to ignore divergent phenomena which cannot be accommodated in the theory at hand (see ibid., 27ff.). Consequently, the question arises how a change in thought styles is possible if this is necessary. How can we perceive something in accordance to a different *gestalt*-concept if the one initially chosen does not fit?

Although Fleck discusses in detail the effects of the harmony of illusion, he does not deny that persistent anomalies can surface in those systems and urge scientists to deal with them (see ibid., 27ff.). On the contrary, he explicitly describes two different stages of scientific observation as a result of such difficulties. Firstly, he mentions a "vague, initial visual perception" which he calls "unstyled" (ibid., 92) and, secondly, the "direct perception of form [Gestaltsehen]" which "requires being experienced in the relevant field of thought" (ibid.). Thus, concrete *Gestaltsehen*, as explained above, is preceded by a weighing of the pros and cons of the various alternatives in order to conceptualise the phenomenon at hand. This balancing of alternatives is made possible by the fact that the individual is simultaneously a member of different thought collectives providing her with divergent suggestions of how best to explain the phenomenon, i.e. what concepts to choose that can provide an explanation expressed in words or pictures known to the scientist.

Here, we can grasp how scientists deal with what is non-conceptually provided by perception to human cognition in their observational processes. It is this epistemic strategy, i.e. the application of concepts borrowed from different thought styles as explanatory means to persistent anomalies, that turns metaphors into the seeds of new theories, and thus offers an explanation of how changes and developments of thought styles can take place (see ibid., 117; Fleck 1986c, 103).

Furthermore, although Fleck seems to think that all that is needed to account for changes in thought styles are communication processes in science and elsewhere (see Fleck 1979, 109f.) and, despite his obvious reluctance to admit the possibility that something can be perceived prior to one's being introduced to the relevant thought style that allows a correct interpretation of the percept,[36] his mentioning of those anomalies[37] suggests that perception provides us with information that cannot arbitrarily be subsumed under concepts suggested by the thought style at hand. The relevant resource to set the stage for anomalies seems to lie in the non-conceptual content of perception that becomes a part of the scientists' observational results.

Taking the above considerations into account, it seems reasonable to assume that both non-conceptual and conceptual contents can be obtained via perception, whereas the former seem to come first. They will partly be substituted by the conceptual content acquired later. Nonetheless, some information will remain non-conceptual in kind even in our later developmental stages. These contents can constitute anomalies within explanatory theories and, as such, motivate further testing which might lead to changes in our theoretical approaches. They can therefore bring about progress in science and are thus of particular importance in this context.

Moreover, as Grundmann points out, adopting an externalist position of justification, i.e. regarding perception as a reliable process of information gathering, also allows us to make knowledge claims based on those non-conceptual perceptual contents (see Grundmann 2008, 497). Consequently, the thesis can be defended that perception not only fulfils its function as an epistemic source if concepts are available for what has been perceived so that observation statements can be formulated as reasons in support of beliefs, but also if those concepts are missing. In this latter instance, it seems reasonable to assume that there is a presumptive right similar to the one highlighted by anti-reductionists in the debate about knowledge by testimony that can be used as a justificatory basis of our perceptual experiences. As Scholz points out, such a presumptive right allows the perceiver to trust her perceptual abilities as knowledge suppliers as long as there are no reasons undermining and defeating this trust, such as indicators of odd lighting conditions or of the previous consumption of hallucinatory drugs, etc. (see Scholz 2009c, 199f.).

But it is not only in this sense that the processes of justification of testimonial and of perceptual beliefs show similarities. As I have argued elsewhere (see Mößner 2010b, ch. 5.5.3), participants in the activity of testimony become increasingly experienced with individuals as testifiers or testimonial contexts during their lifetime. Moreover, it is an important part of our educational system to acquaint students with the relevant practices in their fields of expertise.[38] A similar developmental process can be assumed concerning perceptual experiences. During their professional training, people will usually acquire many of the relevant concepts to verify their perceptual experiences in scientific observations. This becoming acquainted with the relevant concepts as part of the practical training in science is elaborately described by Fleck (see Fleck 1986b). In the next section, we will come back to the process of learning that Fleck explains. For now, it suffices to point out the analogy of development in becoming (a) a trained recipient of testimony in a certain domain and (b) a trained observer in a particular context. It is this developmental progress of the epistemic subject that also allows us to bring in internalist conceptions of justification when concepts are acquired. The observer can then be asked to name the reasons that she thinks support her perceptual beliefs precisely – and they can also be checked for adequacy by others if necessary.

In a nutshell, then, if perceptual experience provides non-conceptual *and* conceptual content in the way argued above, and if it is agreed that the primary way to cognitively access the information transmitted via visual representations is by perception, it does not seem far-fetched to claim that the same mechanisms are also at work in picture perception. Apparently it is these mechanisms that are relevant to consider when enquiring how knowledge might be gained via images in science and how visual representations can make epistemic contributions to scientific arguments. Furthermore, as our line of reasoning moves from the more general case, that is, perception in the broader sense, to the special case, that is, image perception, these considerations also rule out Crane's suggestion, namely that perception is not a propositional attitude, because apparently, picture perception is not propositionally structured either (see Crane 2009). He thus argues conversely, moving from the special case to the general concept of perception. Yet this seems to be an inappropriate way to defend his thesis. In particular, by regarding the issue in converse manner, Crane cannot and does not accommodate the artificial sign character of images in his theory. Yet our ability to decode visually presented information has undergone certain developmental phases because visual representations have become increasingly artificial due to newly developed styles of representation, which has already been explained by making use of the theory of image games.

How to consolidate the theses concerning image perception and those concerning the apparent artificial character of visual representations will be discussed in detail in the next section. The exact implications entailed in pointing to the evolutionarily shaped resource of perceptual experience when analysing potential epistemic contributions of visual representations in science will also be more closely examined.

4.2.3 Evolutionary merits of perception

The question under discussion in this section is whether evolutionary processes that have shaped the development of human vision can be employed in the argument to explain why it might be advantageous to make use of visual representations in scientific discourse. The discussion of this topic will bring into focus our abilities of pattern detection and our discriminatory capacities with regard to colours. However, to mention one constraint to the attempted reasoning by analogy right at the beginning, it has to be taken into account that scientific images have been characterised as signs, i.e. as artefacts. Thinking in this way about the nature of visual representations in science seems to suggest that image perception and everyday perception do not have parity. This apparent difficulty will carefully be considered in the final part of this section.

The capacity of human perception to transmit non-conceptual content is explicitly related to evolutionary processes by Peacocke. He states that "[n]onconceptual representational content is part of our animal heritage" (Peacocke 2001b, 615). Such a line of reasoning arises somewhat naturally from his considerations concerning the perceptual abilities of non-human animals. Here, Peacocke claims that "[I]f the lower animals do not have states with conceptual content, but some of their perceptual states have contents in common with human perceptions, it follows that some perceptual representational content is nonconceptual" (ibid., 614). Admittedly, even lower animals can have perceptual experiences, although they might be different from ours. Moreover, we would usually also assume that, in particular, lower animals do not possess concepts in the way we do or even not at all. Nonetheless, observing the behaviour of those animals suggests that they indeed receive relevant information via their perceptual apparatus to react in accordance to certain stimuli. Thus, it seems reasonable to assume that those animals receive a kind of non-conceptual content via perception (see also Bermúdez and Cahen 2015, sect. 4.3).

Yet a qualifying remark has to be added. Our main concern is with visual perception, i.e. vision, as the predominant human sense modality. Of course, the predominance of vision cannot be so stated regarding other species in general. Some perceptual experiences of animals might be completely different in comparison with human sense perceptions. This is due to some animals being equipped with sense modalities that human beings do not possess, such as a cat's whiskers or the capability of sharks, hammerheads and sawfish to detect the electrical field emitted by their prey.

Here, some interesting questions arise concerning the connection between sense modalities and concepts on the one hand, and concepts and communication on the other. How are our concepts influenced by our predominant sense modalities? Do our concepts evince more details regarding visually perceivable properties (or do we possess more of those concepts?) than regarding properties related to audible, tactile and other forms of perception? Is it because it was more relevant to our ancestors to communicate, for example, visual clues about prey and predators in their environment that our concepts are richer in information regarding visual details than other kinds of information? The archaeologist Steven J. Mithen explains, for example, how a sensitivity to visual information might have been an evolutionary advantage for our ancestors in the context of specialising in certain food supplies.

> Knowledge of carnivore behaviour and distribution would therefore appear to have been critical to early Homo: competing carnivores may have provided both a threat and an indication of a possible scavenging opportunity. In this light it would seem improbable that H. habilis [This ancestor of the human race existed around two million years ago. N.M.] could have exploited the carcass niche *if it had not mastered the art of using inanimate visual clues, such as animal footprints and tracks.*
>
> (Mithen 1998, 115, my italics)

Putting these empirical questions aside, Peacocke definitely has a point when relating the thesis that perception can yield non-conceptual content to the evolutionary development of the human species as visually perceptual beings. In the following, the focus will be on our visual abilities and the discussion of some consequences for images in science as bearers of information resulting from our evolutionarily grounded predisposition to visually access the world.

The opportunity to gain non-conceptual content via perception, and thus to draw on a very rich source of information, may allow us to discover anomalies or new phenomena and even to communicate our findings by integrating images of them in scientific publications. Beyond that, accessing our world visually also enables us to make use of certain strategies of information gathering and processing that are particularly shaped by evolution. Thus, empirical results from the different fields of research about perception should be taken into account. Regarding the analysis of visual representations as bearers and providers of information in scientific discourse, I would like to suggest two further capacities of the human visual sense modality which might alter the balance of the argument when considering the relevance of visual representations in comparison with other representational modes.

Firstly, human observers are obviously good at *pattern detection*. As becomes clear in Mithen's quotation above, the correct reading of – i.e. the correct recognition of behavioural patterns in – animal footprints was of such evolutionary advantage to our ancestors that we can assume it was one of the causal factors in the development of a certain visual expertise in this regard. That, on average, people are indeed particularly skilled in pattern detection makes a more or less current trend in science quite reasonable, namely the initiatives of the so-called *citizen sciences*.[39] It seems worthwhile to select and examine just one of these, namely the project called "Galaxy Zoo" (see www.galaxyzoo.org/, accessed January 12, 2016). Recent sky surveys have yielded huge amounts of data that have to be somehow analysed. "Galaxy Zoo" is part of this analytical project. Here, volunteers – particularly laypeople without special training – participate in classifying galaxies, photographed by space telescopes such as Hubble, according to their shapes. The data are made available online, as well as descriptions of the task, including suggested patterns of what the objects might look like.[40] The user is guided through the classifying task via online dialogues. She can accomplish the required classification without great effort. All that is needed is an *attentive eye* to compare the photograph with the patterns suggested. The project organisers obviously rely on their volunteers' ability to detect patterns. This task cannot be performed at the level of numerical data, i.e. as computational operations by IT devices. There is a certain vagueness involved in classifying these objects that cannot be removed by adhering to numerical data. It can only be reduced by consistent results obtained by various human classifiers. That is, the same object is categorised by several people to minimise the possibility of distorting biases and errors resulting in misclassifications.

It seems to be a consequence of evolutionary processes that human observers are particularly skilled in tasks like this. Thus, making information available in a way that activates these skills, i.e. as visual data that can be investigated by vision alone, can enhance our understanding by connecting these abilities to the cognitive processing of the respective information. In particular, the huge amount of data yielded by today's IT-based research processes, such as measurements recorded as visual data at the LHC in Geneva, the digital photographs taken by the Hubble space telescope, or the data collected in recent sky surveys undertaken in regard to the mapping of the sky by the SLOAN Digital Sky Survey (see www.sdss.org/, accessed January 12, 2016), challenge scientists to think of new ways to evaluate these large data sets. Maynard thinks that the best new ways to achieve this are sometimes rather ordinary old-fashioned ones. "Confronted with the increasingly large data sets from its latest cognitive technologies, our species has fallen back upon its greatest natural information-processing resources, inherited over millions of years: notably those for vision […]" (Maynard, unpublished paper).[41]

Yet, as the practice of multiple visual classification of the same object by different observers shows, scientists are well aware that blind reliance on the capabilities of human observers would be problematic, as the virtues of our visual skills might sometimes turn out to be vices where science is concerned. Hentschel explains this when discussing the capacities of human observers (see Hentschel 2014, ch. 9). His main example are the pitfalls that led scientists in astronomy seriously astray in the nineteenth century when investigating the surface of Mars with their telescopes. Here, he refers to what has become known as the 'Martian canals'. In 1879 the Italian astronomer Giovanni Virginio Schiaparelli published a map of the surface of Mars, showing "thin lines, apparently interconnecting the various oceans (*mares*), lakes (*lagos*) and huge rivers (*fluvius*) […] In later maps, he incorporated a profusion of these thin lines, interconnected in a strange maze-like network mostly originating from one of the *mares*" (ibid., 299). Furthermore, by calling these lines '*canali*', which can be translated either (in the more neutral way) as 'channels' or, in the way most of his contemporaries did as 'canals' (which brings the artificial character of those structures to the fore), Schiaparelli created an illusion which trapped human observers till the end of the twentieth century, namely that these observational results show intentionally brought-about artificial structures on Mars indicating the presence of some sort of intelligent inhabitants on the planet.

However, as Hentschel makes clear, those apparent canals were just the result of the poor resolution of the telescopes used at that time and a certain tendency in human vision to connect isolated dots into lines (see ibid., 307). Moreover, people also seem to have expected to see those patterns after Schiaparelli had published his results. Thus, our ability to detect patterns relatively easily can also result in unintended interpretive impositions of expectations of what is actually visible. Accordingly, Hentschel concludes that:

> [t]he moral of this little tale is that pattern recognition is not an easy business. It can easily go astray, especially if the all-too-human observers are swayed too much by suggestive analogies to well-known terrestrial phenomena. The foregoing is also a lesson about how finicky human vision is. It is optimized to resolve potential threats quickly and thus evolutionarily programmed to over-interpret rather than under-interpret sensory perception. That is why humans are still quicker than modern computer programs in detecting visual patterns. But this speed comes at a price. Our vision occasionally plays tricks on us.
>
> (Hentschel 2014, 309)

Thus, mere reliance on our perceptual abilities alone seems to be not epistemically advisable.

Bearing this in mind, let us turn to the second merit of visual perception that evolution has been working on. Belonging to a diurnal species, the human eye is particularly sensitive to the spectrum of visible light, that is, to a broad range of colours. It has already been noted above that human observers seem to be particularly skilled in detecting even subtle differences in colour hue – even though we often do not have words to term our observations correctly.

With respect to this phenomenon, Karl Schawelka offers an explanation referring to evolutionary processes in human perceptual capabilities (see Schawelka 2007, 64ff.). He draws our attention to the fact that our visual apparatus is adapted to natural sunlight. Although it might be objected that the spectrum of sunlight is very broad and vast parts of it are simply invisible to the human eye, Schawelka makes plain that our visual apparatus is nonetheless perfectly adapted to its tasks. Because of the filtering effect of the atmosphere, not all kinds of solar radiation reach the surface of Earth to the same degree. There is a notable maximum within the range of visible light that is exactly the part of the spectrum that the human eye is particularly skilled in detecting and discerning, i.e. wavelengths between approximately 400 and 700 nm (see ibid., 65).

Moreover, Schawelka highlights an interesting biological finding, namely that the different visual abilities of our perceptual apparatus cannot be simultaneously developed equally well. Apparently spatial perception, colour perception and visual acuity cannot be optimal at the same time. Being particularly good at one of them also implies a loss in those other visual abilities (see ibid., 68). This takes us to the question of what the evolutionary benefits were that stimulated the emphasis on colour vision in the evolutionary development of our ancestors.

A full-blown colour perception appeared as a characteristic of our early ancestors around 35 million years ago (see ibid., 74). Schawelka points out that being good at discerning different colour hues allowed our ancestors to spot, for example, ripe fruits quite easily (see ibid., 72ff.). As omnivores, our ancestors certainly enjoyed the evolutionary benefit derived from this capability of their visual apparatus. It has to be added, however, that further experiences also seem to be of relevance, as colour alone does not indicate digestible food *per se*. Ripe apples and fly agarics, for example, share the same colour, namely red – a particularly salient colour to the human eye (see ibid., 72) – but this does not imply that we are advised to taste the latter. On the contrary, colours can also indicate poison – not only regarding mushrooms and plants, but also insects, fish, snakes and amphibians, such as South American tree frogs. Apparently we also profit from our visual abilities to discern colours easily in this case if the relevant background knowledge is available to us. The colourful skin of those animals will make us deal with them carefully or simply avoid them as soon as we spot them.[42]

John Campbell connects these more general ideas about the evolutionary merits of colour perception to human capabilities of reasoning when pointing out that "[i]t is often observed that colours of objects have predictive value. The particular colours of various foods are predictive of their nutritional value. The exact colours of particular people and plants are good predictors of their health" (Campbell 2009, 35). Campbell here not only highlights the role of colours as indicators of certain properties, such as ripeness or toxicity, but also draws our attention to the way in which our capacity to visually discern colours can be useful in science. In medicine, the colour of human skin can, for instance, be an indicator of certain diseases such as yellow fever or tuberculosis.

Sabine Müller and Dominik Groß discuss the usage of false colour images in medical science and in astronomy (see Müller and Groß 2006). They point out that this kind of visualisation is used especially for two purposes in those domains: firstly, to make visible what is otherwise not accessible to the human eye, but can be detected by other means such as ultraviolet radiation (see Figure 2.2 as an illustration of this point) and, secondly, for supporting the interpretation of images by enhancing their contrast (see ibid., 94). This latter purpose draws explicitly on the ability of human observers to discern between different colours – for example, the photograph of Olympus Mons (see Figure 2.12), in which false colours allow us to identify the different altitudes of the volcano in its different regions without great effort. In comparison with this, extracting the same information from a plain photograph or a greyscale image would be much more difficult. Consequently, as colours are used to transmit information and apparently support recipients in grasping it relatively easily, Müller and Groß defend the thesis that colours can be regarded as *epistemic tools* (see ibid., 114; Groß and Müller 2006, 79).

Despite these advantages of colour vision, it has to be added that, without going into all the details of the debate, there is a particular difficulty related to suggesting colours as scientifically valid indicators of certain states of affairs. Although human observers are usually very good at distinguishing between different colours, the latter cannot be regarded as *objective properties* of the entity to which they seem to be attached. This problem is also addressed in Campbell's text:

> [m]any philosophers – the classical sources are Galileo and Locke – have said that science shows that there is a mistake embodied in our ordinary understanding of colour concepts. We commonsensically take colours to be categorical properties of objects, whose nature is apparent to us in vision, but in fact there are only complex microphysical structures and the consequent tendencies of objects to produce ideas in us.
>
> (Campbell 2009, 40)

What is highlighted by those scholars mentioned by Campbell is that colour is not an intrinsic property of objects, but a phenomenon that is solely present in our perception of those objects. Yet in science we want to find out what the entity under investigation is like, and are not so much interested in the dispositions of human vision to interpret its percepts in certain ways.

What makes matters of colour perception so complex requires two brief explanatory remarks. Firstly, scientists can detect wavelengths of radiation and so measure which parts of the spectrum have been absorbed and which have been reflected by an illuminated entity.[43] Wavelengths are commonly associated with certain colours. Spectrographic analyses in astrophysics, for example, make use of this nexus by assessing the absorption lines of certain kinds of gas in a given spectrum emitted by a particular celestial object to determine the ingredients of a particular nebula or star, yet physicists are reluctant to regard colours inferred from wavelengths of (reflected) radiation as characteristics inherent in those objects. Glenn Elert, for example, states bluntly that:

> [c]olor is a function of the human visual system, and is not an intrinsic property. Objects don't 'have' color, they give off light that 'appears' to be a color. Spectral power distributions exist in the physical world, but color exists only in the mind of the beholder.
>
> (Elert 2014, ch. 3.3.7)

The second aspect that makes matters even more complex is that our perception of colours is highly influenced by a variety of factors outside the assumed bivalent relation between our visual system and the object perceived. What kind of light illuminates the object in question – a warm candlelight or a cold light emitted by a fluorescent tube? What are the surrounding colours like that the object is embedded in? Dark context-colours let us perceive a brighter hue of the object's colour than light context-colours do. Schawelka explains these puzzling phenomena of colour perception in detail. He highlights the fact that context-colours can either contribute to our experience of colour consistency or, to the contrary, trigger the phenomenon known as 'simultaneous contrast', that is, two physically identical stimuli that can result in two totally different colour experiences depending on the context-colours of these stimuli (see Schawelka 2007, 49). It therefore seems rather difficult to refer to our ordinary perceptual abilities to detect certain colours as a reliable tool of scientific analysis. In order to achieve reliable results, what seems to be required is the use of instruments unaffected by such distorting visual phenomena; instruments that can deal with these problems by abstracting the objective value from those additional factors.[44]

To sum up my results so far, the above considerations suggest that evolutionary processes have provided human beings with particular visual skills. On average, we are able to gather a wide range of information via visual perception, even if this is non-conceptual in kind. Moreover, nature has endowed us with certain detective abilities, especially with respect to grasping patterns and colours, that have enabled us to quickly focus our attention on aspects of vital interest in this wealth of information. Those abilities were apparently advantageous to the survival of our ancestors – and can still be useful in the everyday context as well as in the sciences.

The usefulness of those skills in epistemic contexts is defended by educational psychologists. In particular, Eleanor Gibson's work on *perceptual learning* is based on the discriminatory abilities of human sense perception. Benedict Carey explains how learning is considered in this context. He writes:

> [p]erceptual learning is active. Our eyes (or ears, or other senses) are searching for the right clues. Automatically, no external reinforcement or help required. We have to pay attention, of course, but we don't need to turn it on or tune it in. It's self-correcting – it tunes itself. The system works to find the most critical perceptual signatures and filter out the rest.
>
> (Carey 2014, 184)

Carey points out that quite a few computer-based learning programs take advantage of perceptual learning. Such tools are, for example, used in flight training to teach trainees "perceptual intuition" (ibid., 188). The dials of six main instruments in the cockpit of a small aircraft are displayed on a computer screen, and the trainee is asked to choose between seven different options of what these instruments tell her in sum about the position and activity of her plane. She is thus trained to make her choices just by looking at her instruments and not by considering each of them in detail, trained to develop a gut feeling, so to speak, about what those instruments in sum tell her, as flying means multitasking, especially during landing manoeuvres. That is, the pilot not only has to read her instruments, but also talk to the tower, consider visual information, perform the necessary tasks – and all of this more or less simultaneously. Thus, the pilot simply does not have the time to read and interpret each instrument separately, but needs to base her decisions on a quick look at them.

This example of training tools drawing on perceptual learning makes clear that human observers are particularly good not only at discriminating between relevant perceptual clues, but can also become even better at this task through regular visual training. Carey's examples thereby support the suggestion that, because picture perception draws on these evolutionary resources, using visual representations as a means to transmit information in scientific discourse allows us to profit from these virtues of our visual apparatus.

Moreover, this line of reasoning offers a rationale for the epistemic qualities of images of various kinds, as pointed out in Perini's work, for example. She shows that, for instance, micrographs can inform us about spatial features of the specimen, even if we do not have concepts to verbally describe what we have observed by inspecting the image. She claims that these images

> can represent unfamiliar phenomena, without the need to articulate hypotheses about results prior to the experiment. As in this case, figures that support the existence of unexpected structural features can be produced. This system can also represent very complicated structural properties, even when there are no linguistic terms for the same features.
>
> (Perini 2005c, 921)

In a similar fashion, Kulvicki's claim that images can transmit vast amounts of information across various levels of abstraction more or less immediately (see Kulvicki 2010b) can be explained with recourse to the epistemic merits of the perceptual abilities of human observers.

Caution is definitely advisable, however, that optimism about similarities between picture perception and perceptual processes in general is not misleading us when analysing the epistemic capabilities of scientific images. Maynard stresses that there are important differences between both perceptual processes (see Maynard 2011). He highlights the fact that images[45] are *artefacts*. Acknowledging this implies that it has to be taken into account that people are accustomed to handle artefacts in certain ways. This means that they regard visual representations as being produced for certain purposes, which they then try to identify when looking at images. This is why Maynard thinks that picture perception is, at least to a certain degree, different from visual perception in everyday life. Moreover, this crucial distinction is also his rationale for rejecting an unqualified application of theories of visual perception to picture perception. He writes that:

> '[v]isual array' treatments of pictures dominant in philosophy and perceptual psychology ignore these basic features about perception. Overlooking that depictions are familiar artifacts and used as such, they neglect the great differences between looking at things and looking at depictions of them. Notably, they hide the fact that we look at depictions, not real scenes, for their depictive 'for' affordances, and in terms of 'on purpose': why they were put or left there, what they are *doing* there – including whether they should be there.
>
> (Maynard 2011, 21)

Thus, although the deciphering of visual representations in science might benefit greatly from being based on perceptual processes that allow the investigator to rely on cognitive mechanisms especially shaped by evolution, Maynard is obviously right in reminding us of this difference between ordinary and picture perception. Following his advice seems to be most crucial with regard to the initial thesis, namely that visual representations in science can best be understood as *signs*. However, acknowledging this artificial character of images in science does not undermine the possibility of drawing on the cognitive resources provided by visual perception. An explanation is due at this point. In section 4.1.3, and with reference to Scholz's concept of *image games*, we already discussed the possibility of a layering of meanings in visual representations; that is, the addition of new layers of meaning to its initial encoding by making use of images in communicative contexts. It is here that interpreters of scientific images will be most attentive to their object's artificial character and question the intentions of those people who either produce or distribute those images. It was suggested that strategies of justification developed in the debate about knowledge by testimony concerning the epistemological role of visual representations in scientific discourse be employed to deal with this situation. Those models of justification are primarily based on assumptions about the speaker and only secondarily on considerations about the content transmitted, such as its coherence with background beliefs. Thus, Maynard's reminder does not pose a counter-example to the above line of reasoning.

As a concluding remark, I want to highlight another finding of Maynard's analysis concerning the cognitive content of visual representations. He emphasises that adhering to the results of perceptual sciences too strictly might lead to an unwanted consequence concerning the epistemic status of (scientific) images, namely that they are regarded as external to the human mind, i.e. as objects of visual investigation similar to natural entities (see Maynard 2011, 11). Such an externalist conception apparently speaks against the possibility of using images as signs that can be purposefully produced to transmit information. Contrary to this, no problems of this kind have ever been asserted with respect to language. Maynard not only notes this discrepancy between estimations of the epistemic capabilities of images and of verbal language on the part of scholars relying on perceptual sciences to explain the epistemic accomplishments of visual representations, but also traces this stance in the analyses of evolutionary palaeoanthropologists who theorise about the origin of the human mind and the capacities of our ancestors to communicate via symbolic means (see Maynard, unpublished paper).

Maynard points out that although scholars of this profession often use cave paintings as evidence of our ancestors' developing capabilities to communicate by using symbols, they more or less immediately deny visual representations their epistemic roles.

> Returning to the standard image-to-language reasoning, it is interesting that once we have used image thought-content to infer the advanced

> linguistic kind in the Ice Age, we put aside and even deny the former. In Philosophy, as in science, the Paleolithic evidence is swiftly awarded the honorific title 'art', allowing us to treat it as something outside the mind [...]
>
> (Maynard, unpublished paper)

Such a negative stance towards images as content providers is expressed for example by David Lewis-Williams, an expert on cave paintings. He writes that:

> [t]he best that can be said for pictures is that they trigger memories of information that has been absorbed in different ways, that is, by experience and verbally. So whilst the Upper Palaeolithic images may have sometimes functioned as mnemonics, their capacity to store or convey information was limited. They were not like the hard drives of modern computers.
>
> (Lewis-Williams 2004, 67)

Without doubt, Lewis-Williams suggests an epistemically inferior status for those visual representations produced by our ancestors in comparison with their first verbal utterances. He particularly denies that those images can possess a kind of cognitive content similar to linguistic expressions that allows the storage and transmission of information.

However, there are other scholars working in this field who see less of a discrepancy between the epistemic capabilities of linguistic and visual representations. Mithen's opinion about this topic offers, for example, an interesting contrast to the sceptical attitude diagnosed by Maynard. About the contributions of those early visual representations to the information process he states that:

> [i]n summary, although the specific roles that prehistoric artifacts may have played in the management of information about the natural world remain unclear, *there can be little doubt that many of them served to store, transmit and retrieve information*. Major benefits of this will have been enhanced abilities to track long-term change, to monitor seasonal fluctuations and to devise hunting plans. Many of the paintings, carvings and engravings of Modern Humans were tools with which to think about the natural world.
>
> (Mithen 1998, 197, my italics)

I agree with Maynard that the link between those early visual representations and language as tools of communication is apparently better understood along the lines of Mithen's reasoning than of Lewis-Williams's. What reasons are there to deny that those images were meant to transmit information encoded by those early artists?

Taking this as background information for the analysis, it seems reasonable to assume that visual representations can bear a cognitive content and thus play an epistemic role in communication. Moreover, acknowledging this fact also prepares for taking into account the long history of this practice of visual communication. That is, long before mankind developed symbols to record language, a way to transmit information visually via those images had been established. Moreover, not only does visual communication greatly pre-date the use of writing skills, it also has lasted much longer. Our ancestors made use of this practice for around 30,000 years, as Lewis-Williams claims: "[s]till, radiocarbon dating strongly suggests that the Upper Palaeolithic period, that part of the Palaeolithic in which people began to make art, lasted from about 45,000 to 10,000 years ago" (Lewis-Williams 2004, 39), and we still use images in our communicative habits today. Thus, comparing this rather impressive time-span with the few thousand years of our practice of writing, it should come as no surprise that human beings had already developed considerable skill in encoding and decoding visual information. Thus, it is not only the evolutionary development of human vision that allows us to benefit epistemically in processes of deciphering visually presented information, but also this long-term social practice.

4.2.4 Interim results: what can be learnt from theories of perception?

The above discussion of the cognitive content of visual representations in science was motivated by Perini's initial observation that it seems to be common practice in scientific discourse to use images when attempting to transmit essential information about research results, hypotheses and methodology. Hentschel points out that there are 14.8 images per ten pages of text in contemporary scientific journals in biology and 12 images per ten pages of text in physics journals (see Hentschel 2014, 30). It seems, then, that scientists share a particular preference for making use of visual representations to transmit certain information.

Despite this widespread practice, philosophers question the epistemic capabilities of visual representations in scientific discourse, as Perini has made clear. In particular, they express reservations about the suitability of visual means to be regarded as proper components of scientific arguments – whereby 'proper components' refers to the assumed epistemic capacities of images. The above analysis was thus intended to inquire more deeply into the prerequisites of these capacities and, especially, the question about the precise nature of an assumed cognitive content of scientific images had to be answered.

With regard to the epistemic capabilities of visual representations in the context of scientific arguments, proponents of the traditional Fregean point of view seem to regard 'argumentation' as an exclusively verbal activity. Their main objection, then, consists in the fact that images are apparently not propositionally structured. As their line of reasoning suggests that epistemic functions are tightly bound to propositional contents alone, they think one is seemingly entitled to disregard visual representations as epistemic means in this context.

Contrary to this, a different account has been presented here, as it can be assumed that Perini is correct in pointing out that scientists handle those visual elements differently from the way proponents of the Fregean point of view would suggest when affording them a role in scientific discourse, and that it would be wrong to disqualify such practices from an epistemological point of view.

The first suggestion, already argued for in the last section, stipulated starting with a different account of 'argumentation', namely to regard argumentation as a communicative act that can be identified via a certain intention of the speaker and which can be performed by using different representational means. Stripping off the too narrow conception of mere verbal utterances has made it possible to take into account the epistemic achievements of visual representations in the context of scientific discourse more seriously. Apart from Kjørup, whose work we have used as a guideline in this respect, other scholars – in particular those working on argumentation theory – have suggested similar, albeit more broadly conceived methodological approaches to the topic of argumentation.[46]

Yet, although this initial shift in perspectives allows us to take epistemologically seriously the phenomenon of visual representations, the first question that still has to be answered refers to the kind of cognitive content such images might contain and are thus able to transmit in the argumentative context. In this respect, the point has already been stressed that we are apparently able to translate contents from one representational means into another. This holds true also in the case of images and therefore speaks in favour of the thesis that at least some of them contain a cognitive content that can be transmitted in communicative acts.

The question of translatability has triggered another critical point, namely whether scientific images are only auxiliary means in the distribution of content, i.e. whether the choice of a visual presentation of information is only due to the weakness of the human mind to grasp the data otherwise.[47] Philosophers, highlighting this (in principle) reducibility of visually transmitted information, suggest that visual representations do not contribute to the acquiring of *scientific knowledge or other epistemic desiderata*, although, from a *practical point of view*, images may be preferable to other kinds of representations in science. Irving, for example, mentions this sceptical philosophical stance appearing in the discussion about the epistemic value of images in scientific arguments (see Irving 2011, 775).

The suggestion to reduce visually presented content to a presumably epistemically more basic category is critically commented on by Perini. She refers to the reducibility thesis as a putative rationale for why philosophers of science apparently take it for granted that visual representations are not worth analysing as epistemic tools. As Perini states, this neglect reveals "an underlying assumption: The reasoning involved when scientists support hypotheses with figures can be understood without considering visual representations as such" (Perini 2005c, 914). However, neither Perini nor I are convinced by this line of reasoning, as it completely ignores scientists' preferences for visual representations in their reasoning practices.

The question of how to argue for an *independent epistemic status* of scientific images then took us back to the debate about propositionality. If we want to defend the thesis that visual representations can yield knowledge or other epistemic desiderata, we apparently have to discuss first what kind of content – propositional or non-propositional – they can contain and transmit. In the response to this query, we focused on the fact that it is *via perceptual means* that we decipher the content of scientific images. Apart from the sceptics, most contemporary philosophers agree that perception can be regarded as an epistemic source, i.e. as a source of propositional knowledge, thus, pointing to the fact that cognitively accessing the content of images via vision also permits drawing an analogy to everyday perception. That is, if it is admitted that perception in those everyday contexts yields propositional knowledge, then this epistemic mechanism should not be called into question when scientific images are visually investigated. The view has therefore been endorsed that at least some visual representations can transmit a propositional content.

Yet a more detailed look at the topic has made clear that there is more to the epistemic dimension of visual representations than simply propositional knowledge via perception. In particular, Hentschel's example of the first observations of the solar surface has made plain that our visual capabilities are not restricted to already-conceptualised domains. On the contrary, human observers are apparently able to detect vast amounts of information via their visual apparatus, even though they do not possess relevant concepts to name and describe correctly what they have observed. This is not only true with regard to people presumably lacking the relevant individual training in technical vocabulary, it also holds true even if there are no suitable concepts available *per se* – as in the case of the images produced by electron micrographs discussed by Perini.

In this sense, I also partially agree with Grundmann's thesis that our perceptual apparatus allows us to access non-conceptual and thus non-propositional content as well. This seems to be how perception genuinely works. Concepts to classify what we see are often acquired when other people – parents or teachers – explain to us what we have observed. Thus, those concepts are acquired via testimony, that is, by the words of others, that accompany, as explanations, observational situations particularly in our early years. Here, testimony and perception work hand in hand to form the basic knowledge on which our belief system is built. When the relevant concepts are acquired in the way described, it does not seem so far-fetched to assume that we are also able to gain propositional knowledge via perception.[48] The suggestion, then, is that some visual representations can transmit both kinds of contents – propositional and non-propositional alike. In particular, representational images such as photographs or instrumentally produced images such as micrographs, brain scans, or computer graphics, seem to let the observer benefit from her perceptual ability to detect and decipher non-conceptual as well as conceptual contents.

Finally, taking into account that it is via perception that information, transmitted by visual representations, is cognitively accessed, has also made plain why we are obviously particularly skilled in decoding information presented in this way. Empirical evidence supports the thesis that visual perception has developed as a cognitive resource for human beings that has been especially shaped by evolutionary processes. In accordance with this, Hentschel claims that "[a]pproximately 60% of the input into the human brain comes from vision" (Hentschel 2014, 32). Not only do we gain huge amounts of information via our perceptual apparatus, even if we do not possess relevant concepts of what we see, but human vision has also evolved in such a way that we are, for example, particularly good at pattern recognition or detecting colour hues.

Therefore, choosing visual representations to transmit information in scientific discourse also means attempting to benefit from these cognitive advantages provided by those evolutionary processes. Diagrams and graphs, for example, are particularly useful to exploit our ability of pattern recognition. Photographs and other images brought about by causally functioning instruments are especially suitable as evidence, because they can transmit information otherwise only available to the initial observer – the eye-witness, so to speak. Furthermore, acknowledging the capacity of images to transmit even non-conceptual content enables scientists to draw on the further merits of visual representations. On the one hand, scholars can start communicating about phenomena that have not yet been completely conceptualised. That is, visual representations allow scientific collaborative investigations even when no clear concepts of the phenomena are available. They not only allow working out the details, but also the elaboration of the initial concept itself. On the other hand, the fact that images can transmit non-conceptual contents also explains how it might be possible that such visual representations can be used to refute certain hypotheses in science. Their content might reveal to subsequent observers anomalies or new phenomena not expected by the initial investigators. Photographs taken by astronomers can illustrate this point. Ratzka explains that, although those images were initially not intended for this purpose, early photographic recordings are re-evaluated nowadays to check for detections of the movements of asteroids – a phenomenon not known to those early astrophotographers (see Ratzka 2012, 246). Used this way, those pictures refute the initial hypothesis that all the detected entities were stars.

All of these aspects add to the explanation of why many scientists favour visual representations in their communication processes. Moreover, it also suggests an explanation for the reason that certain academic disciplines are more attached to such a visual method of information transmission than others: in particular, empirical sciences apparently profit from the evidential role that visual representations can play in scientific discourse. Moreover, scientific disciplines that produce huge quantities of numerical data – as the results of measurement or simulation processes – benefit from the human cognitive capacity to evaluate visualisations rendered from those data sets.

The final remark in this summary is meant to bring into focus a crucially divergent aspect between everyday and picture perception as highlighted by Maynard. He urges us to keep in mind that it would be wrong to claim a complete identity in this respect. Most of all, we have to be aware of the fact that it is a part of the recipients' background knowledge that visual representations are artefacts, i.e. that they are created and circulated within the community for certain purposes. Scientists will therefore usually take into account the intentions of the communicating party when evaluating visual representations in scientific discourse.

The suggestion, in this regard, was to make use of Scholz's account of image games. This approach explains how a layering of meanings can take place, that is, how initially encoded information can be enriched by the intentions of different people making use of the genuine image in diverse communicative settings. In this way, the apparent tension between regarding scientific images as signs and as entities subjected to a basically perceptual decoding can be relieved. Moreover, as the theory of image games allows us to endorse the artificial character of scientific images despite their perceptual decoding, we can make use of their sign character to help explain why certain visual representations are more easily understandable than others. Some – such as photographs – are more closely related to our capabilities of perceptual decoding than others, for example diagrams whose interpretation requires more training, that is, background knowledge.

Having laid out my hypotheses on the relations between the perceptual abilities of human observers, the cognitive content of visual representations and the functional roles of images in scientific discourse, I will next discuss what effects these findings might have on an epistemological evaluation of scientific images.

4.3 The cognitive value of visualisations

The above considerations about the perceptual deciphering of visually presented information suggest two points about the epistemic status of scientific images. Firstly, the thesis has been defended that at least in those instances where the relevant concepts are at the observer's disposal, propositional knowledge can be gained via picture perception. Moreover, the acquisition of these concepts is often made possible partly by our perceptual abilities. Secondly, the discussion of non-conceptual contents being grasped via perception and the correlated capacity of some visual representations to transmit such a kind of information suggests that, from an epistemological point of view, there is more to the epistemic status of these visual means than being sources of propositional knowledge alone.

In sum, the above analysis shows that claiming a necessary inferiority of visual representations in comparison to other representational means when information transmission is at issue – a claim that proponents of a traditional Fregean point of view might defend – is not justified. On the contrary, in the previous discussion it was pointed out in what sense images might entail a cognitive content which can be used for such knowledge-orientated communicative purposes in science. Acknowledging the fact that 'visual representation' is a broad category of diverse visual phenomena which might also be of mixed qualities when it comes to transmitting their content to a respective audience, it seems reasonable to assume that by and large visual representations have parity with other communicative vehicles expressing thoughts.

In this final section, the focus will be on the question of whether visual representations are particularly suitable to serve specific epistemic functions in science. Can the thesis be defended that, at least in certain instances, images can be regarded as *epistemically superior* to other representational means when it comes to fulfilling particular communicative tasks?[49]

In the following, the question of the precise *cognitive value* of visual representations in scientific discourse will be discussed. Is there a kind of epistemic advantage inherent to visual representation not present in other vehicles of communication? To find an answer to this, the role of images in learning activities in science, i.e. within a paradigmatic epistemic process, will be examined, whereby the concept of learning is meant here in a broad sense and not merely confined to students' education. On the contrary, *learning* is commonly understood as an essentially cognitive activity.[50] Being successful at learning something normally implies two important epistemic desiderata: *knowledge* and *understanding* (see Kosso 2007, 175).

Both of these epistemic desiderata will be discussed separately in the following analysis. The investigation is guided by the questions of how visual representations fit into the epistemic process of learning, what exactly their contributions in this context are, and how they can support the cognitive aims of learning. In this context, some of the insights will be applied that have been gained concerning the cognitive content of visual representations and the perceptual way they are utilised so that their content is understood. That some visual representations can transmit non-propositional content provides a resource to take into account suggestions discussed in epistemology beyond the traditional point of view, which focuses solely on propositional knowledge.

Firstly, with regard to knowledge acquisition, this means that the question to be asked is in what sense visual representations can contribute to (1) *knowledge-how* or to the attainment of (2) *mental images* via phenomenal knowledge or via knowledge by acquaintance. Both ways allow for knowledge representations beyond propositionally structured contents. Moreover, philosophers traditionally assume that a disregard for these kinds of knowledge in epistemological analyses is justified because, among other things, they can neither be transmitted in conversation nor can logical operations be utilised to process them further (see Grundmann 2008, 86). If it can be shown, however, that they are indeed communicable, namely by means of visual representations, this would not only add to the cognitive value of images in scientific discourse, it might also return into focus those other kinds of knowledge in epistemology.

The second dimension of successful learning, namely *understanding*, is related to a discussion in epistemology similarly motivating a critical dispute about the exclusive focus on propositional knowledge. Triggered by the struggles of analytical philosophers to come up with a convincing concept of knowledge in the aftermath of the Gettier-cases, which undermined the traditional analysis of 'knowledge' as justified, true belief, philosophers started discussing what is really to be appreciated as valuable with regard to knowledge by advancing the questions of the epistemic value of knowledge in comparison to mere true belief and whether there are other epistemic desiderata epistemically worthwhile to consider. In this context, the suggestion has been put forward to regard understanding as an epistemic desideratum with an intrinsic epistemic value (see Kvanvig 2003, 186). Some philosophers even propose to replace 'knowledge' with 'understanding' in epistemological analyses. Thus, discussing how visual representations can facilitate scientific understanding, would also mean showing how they can contribute to an epistemic desideratum valuable in its own right, that is, independent of propositional knowledge.

Considering possible contributions of visual representations to both the acquisition of other kinds of knowledge and to the facilitation of understanding in science therefore means investigating the cognitive value of images beyond the classical setting of the distribution of propositional knowledge.

To attain a better understanding of the topic, the analysis will begin with a discussion of approaches from the realm of educational psychology, in which scholars investigate the effects of visual representations on learning processes from an empirical point of view. Choosing this empirical perspective as a starting point for subsequent epistemological discussions has the advantage not only of showing exactly how images can play a part in the cognitive process of learning, but also of highlighting the constraints on their efficiency in this context, constituted for example by learners' characteristics.

4.3.1 Educational psychology

In this section, some theses will be examined concerning the effect of visual representations on learning processes put forward by educational psychologists. A comprehensive overview of this topic is presented by Ioanna Vekiri (see Vekiri 2002). She discusses three different theoretical approaches from the realm of educational psychology to explain the contributions of graphical displays to students' learning processes. Regarding the educational merits of these visualisations, there are, on the one hand, those theories dealing with the positive effects on *remembering information* (see ibid., 262). Accounts on *dual coding* and *conjoint retention* belong to this set of theories. On the other hand, there are approaches, subsumed under the heading of the *visual argument hypothesis*, dealing with the transmission and processing of information offered visually.

Vekiri focuses her analysis exclusively on graphical displays such as diagrams. It can be assumed, however, that other kinds of visual representations show similar effects on learners' cognitive processes. I will point out possibilities of an application to a wider range of images in the discussion of the different theoretical approaches below. Furthermore, we will focus on dual coding and visual arguments accounts alone, as the theory of conjoint retention does not add a new dimension to the topic of enhancing students' cognitive processes. It is based on the dual coding approach and applied to the realm of maps, thus constituting a case rather of application than a completely new theoretical approach, as Vekiri makes plain (see ibid., 292).

Proponents of the theory of *dual coding* suggest that there are two different cognitive subsystems in the human mind: one to process and store verbal information and another to process and store non-verbal, in particular visual, information (see ibid., 266). Vekiri points out that, despite this assumed duality, proponents of this theory nonetheless argue for a linkage between both systems. "Although the two cognitive systems are functionally distinct, they are interconnected. Associative connections can form between the verbal and visual representations, enabling the transformation of each type of information into the other" (ibid., 267). This connection between both systems is, for example, used to explain why people are able to mentally visualise certain events read in a novel. Moreover, Wolfgang Schnotz defends the thesis that the theory of dual coding not only affects graphical displays but also pictorial representations such as photographs (see Schnotz 2002, 107).

A consequence of the theory of dual coding for educational purposes consists in the thesis that it is advantageous to present information both visually and verbally in this context, for example by adding visual illustrations to a text. Two explanations are offered why such a combination of representational means can enhance the student's cognitive process of learning if certain design criteria are met.

The first aspect concerns the retrievability of information processed and stored in such a dual way. Vekiri describes the potential positive effect on learning processes as follows:

> [i]llustrations and other visual materials may contribute to the effectiveness of instructions by enabling students to store the same material in two forms of memory representations, linguistic and visual. When verbal and visual information is presented contiguously in time and space it enables learners to form associations between visual and verbal material during encoding.[51] This may increase the number of paths that learners can take to retrieve information because verbal stimuli may activate both verbal and visual representations.
>
> (Vekiri 2002, 267)

Obviously, this dual method of cognitively storing and accessing information can be valuable not only in the educational setting that Vekiri discusses, but also in the cases of measurement data shown in diagrams and discussed in the related text in a scientific article or textbook, for instance, where the very same effect can obtain, namely that two different memory traces might support the process of learning the relevant results.

A second way in which the dual coding theory can be used to explain an enhancement of students' learning processes, when visual and verbal information is presented in the right manner, concerns a reduction of the cognitive load on the working memory, presumably achieved by offering visual information.

> Dual coding theory claims that visual representations can be accessed as a whole and processed in a simultaneous manner, whereas linguistic representations are hierarchically organized and processed sequentially, one piece of information at a time. It is likely that graphics can improve our memory of verbal material because, owing to working-memory limitations, their mental reconstruction allows faster and more effective processing than does verbal representations.
>
> (Vekiri 2002, 279)

Again, such a positive effect can be assumed to obtain in the scientific setting as well as in educational contexts.

Apparently the theory of dual coding is a very successful approach to explain learning processes. Vekiri points out that recent studies in neuropsychology and cognitive science seem to have proven the theses put forward by proponents of the dual coding theory empirically (see ibid., 267ff.). However, this theoretical approach can account for the relevance of visual representations in the epistemic processes of science to a certain degree only. The following two reasons make especially plain the minor explanatory status of dual coding approaches in this realm.

Firstly, the dual coding theory somehow presupposes a certain redundancy in information presentation, i.e. the described positive effect is achieved best if visual and verbal information overlap significantly. This way of presenting information, however, cannot always be expected to obtain in scientific discourse. Adhering to dual coding by all means would undermine Perini's thesis that scientists use visual representations as proper components of premises and conclusions in scientific arguments. The crux is that Perini's argument presupposes (and I have also tried to show this in the above discussion) that certain kinds of information – for example non-conceptual contents – cannot be transmitted by verbal representations. Thus, not all kinds of information can be as equally well-presented by visual and linguistic representations as is apparently presupposed by proponents of the dual coding theory.

Secondly, the theory of dual coding has an emphasis on remembering and ways of retrieving information from our cognitive system. These are, admittedly, important aspects of learning. However, there are further aspects of visual representations in scientific communication and scientific discourse that draw on cognitive abilities not covered by dual coding. As an example, the possibility of detecting anomalies undermining prevalent scientific hypotheses to explain certain phenomena was pointed out above. Moreover, scientific images often serve as evidence to support certain theses in science and are, as such, subjected to critical investigations by an audience. None of these functions is particularly related to memorising or retrieving information, that is, the subject matter of the dual coding theory. Consequently, the theory of dual coding is only of partial interest when the epistemic status of visual representations in epistemic processes in science is scrutinised.

The more interesting account in the present context is the so-called *visual argument hypothesis*. Here, the label 'visual argument' might be slightly misleading as proponents of this approach are not concerned with arguments in the philosophical sense. Thus, we are not discussing the validity or structure of arguments, namely premises, conclusions and inferential reasoning, rather this psychological approach focuses on the ability of visual representations to transmit information and to enable the recipient to grasp complex relations existing among them.

> Visual argument concentrates on the perceptual and interpretation processes that take place when learners extract meaning from graphical representations. It claims that graphical displays are more effective than text for communicating complex content because processing displays can be less demanding than processing text.
>
> (Vekiri 2002, 262)

Proponents of this account state that visualisations enhance the process of learning at the following levels:

1 Such representations offer information both about their individual elements and their relations (see ibid., 281). Graphical displays make it easier for recipients to learn about those elements and they support inferences about their relations simply by looking at the depictions. This perceptual feature allows for further merits of visual representations in cognitive processes.

2 In particular, it provides for "computational advantages" (ibid.). That is, recipients do not have to search a body of text for the relevant information "and then store it in working memory while searching for the next relevant piece" (ibid., 282) – a process that is "prone to error because working memory has limited capacity and cannot maintain data for a long time without constant attention" (ibid.), as Vekiri points out. Visual representations allow this information to be externalised while keeping it constantly present before the reasoner's eyes. In this way, not only is the cognitive load reduced and capacities thus saved for further reasoning, but also the likelihood of errors is diminished.

3 Relying on their perceptual capabilities in deciphering visually presented information can enable recipients to draw inferences almost automatically about the information offered, instead of involving them in long interpretive activities (see ibid., 282). Just by looking at a bar graph, the student may *simply see* a difference in length expressing a difference in quantity.
4 Visual representations can support the recipients' cognitive processes by providing them with a concrete mental image that can help to work out the solution to a problem in the following way: "[w]hen people reason about a problem using symbolic representations they do not have to mentally carry out all the thinking processes but, instead, they can think of a solution by manipulating parts of visual images. Reasoning often requires consideration and evaluation of alternative possibilities" (ibid.).[52]
5 Finally, and linking the current discussion to what has been previously said about dual coding, presenting information visually "may trigger the recall of relevant knowledge" needed for ongoing reasoning processes (ibid., 283).

This last point, as well as the penultimate one, do not seem to restrict themselves to graphical displays but exhibit an advantage, rather, in the processes of reasoning facilitated by all different kinds of visual representations. I would therefore claim a broader applicability for the visual argument hypothesis than Vekiri does in her article. However, care should be taken not to overemphasise the advantages mentioned, as they are dependent on at least two further conditions.

Firstly, visual representations can be more or less apt for particular communicative purposes. Quite a few scholars discuss how to improve the design of visual representations to have them result in a higher efficiency. Vekiri mentions design guidelines for graphical displays (see ibid., 301ff.). Suggestions with respect to graph design are, for example, put forward by Priti Shah and James Hoeffner (see Shah and Hoeffner 2002, 62f.). Alexander Renkl and Katharina Scheiter discuss proposals of design enhancements on a more general level (see Renkl and Scheiter 2015, online first).[53]

Secondly, learner characteristics play a significant role in creating the epistemic advantages of visual representations in cognitive processes (see Schnotz 2002, 113f.). Although a variety of aspects are discussed in this regard,[54] the most significant factors seem to be related to the following abilities, highlighted by Schnotz:

> [v]isuo-spatial text adjuncts and other forms of visual displays can support communication, thinking, and learning only if they interact appropriately with the individual's cognitive system. Accordingly, the effects of visuo-spatial adjunct aids depend on *prior knowledge, cognitive abilities, and learning skills.*
>
> (Schnotz 2002, 113, my italics)

The topic of prior knowledge will be briefly examined at this point.

Apparently this category contains two different kinds of knowledge, one related to the depictive style of the visual representation presented to the learner and another connected to the informational content of the image at hand. The former aspect seems to be naturally relevant, as beyond naturalistic depictions, ways of visualising information have been increasingly developed. This developmental process has been accelerated significantly by the possibilities offered by IT devices within the last few decades. Thus, it comes as no surprise that people have to learn new depictive styles to correctly decipher information presented with their aid. However, this does not undermine the previous thesis that we can nonetheless draw on our perceptual abilities and, therefore, on evolutionarily manifested advantages of processing visual information when decoding visual representations. For instance, pattern detection can be made to work even though we are not familiar with a particular style of depiction. Thus, what we are facing here seems to be similar to what happens in the course of concept acquisition: we can receive information via our perceptual apparatus even if we do not possess the correct concepts of what we perceive. Yet our abilities as observers can be improved significantly by acquiring the relevant concepts.

The second, content-related aspect of background knowledge seems to be more controversial in the debate. On the one hand, scholars suggest that more background knowledge in the related domain enhances the cognitive efficiency of visual representations used for purposes of information transmission (see Vekiri 2002, 304).[55] On the other hand, it is pointed out that more background knowledge might diminish the cognitive value of visual representations as recipients can, for example, visualise relevant details by reading a text alone (see e.g. Schnotz 2002, 114). Moreover, it is argued that people equipped with a higher degree of background knowledge might also be more tempted to disregard visual representations as relevant sources of new information and simply experience them as an entertaining side-effect. Renkl and Scheiter discuss this learners' bias, that is, the tendency to ignore information presented only visually, as one of the main problems affecting the use of visual representations in educational environments (see Renkl and Scheiter 2015, online first).

It seems reasonable to assume that a higher degree of background knowledge can cause both effects, namely a better understanding and a tendency to neglect information presented in a visual way, as these are no contradictory effects *per se*. Only their contingent combination will, without doubt, undermine the positive effect that images might have in this context. Renkl and Scheiter stress a point important in the context of education. Apparently students have to be instructed to acknowledge the relevance of visually presented information correctly. However, the neglect mentioned here does not extend more generally to the context of scientific discourse. Scientists publishing and reading articles usually acknowledge the relevance of visual representations, as illustrated above, by drawing attention to the invention of the database INSPIRE in the natural sciences that allows the storage and search for visual information separately (see www.projecthepinspire.net, accessed February 16, 2016).

Beyond that, scholars in educational psychology suggest that presenting information visually is particularly helpful to students with low prior domain knowledge. As Schnotz states: “[p]revious research has pointed out that comprehension among learners with low domain knowledge (but sufficient visuo-spatial cognitive skills) is increased when pictures are added to a text” (Schnotz 2002, 114). Again, this seems to be a reasonable claim, as visual representations can guide the learner’s attention to notice the relevant details, can highlight relations otherwise overlooked, or present complex information in a significantly simplified fashion. To be concise, students’ prior knowledge seems to be a somewhat ambiguous condition influencing the process of learning by using visual means.

Summing up the previous discussion, it can be stated that, after recipients have mastered the initial obstacles to work with visual representations effectively (which is often part of their scientific training), the latter can, according to the visual argument hypothesis, support the cognitive process of learning on at least three different levels: firstly, by showing the relation between individual pieces of information; secondly, by making information directly perceptually accessible; and, thirdly, by enabling a more efficient use of cognitive resources. This last aspect is highlighted by Vekiri. “Also, displays support thinking during problem solving because they reduce the amount of information that must be maintained in working memory” (Vekiri 2002, 288). Moreover, that visual representations indeed bring about these theoretically proclaimed advantages is demonstrated by several empirical studies cited by Vekiri and others.

Provided with this empirical background information concerning the cognitive effectiveness of visual representations, the epistemological analysis can now be continued. What exactly the contributions of images might be to the two components of cognitive processes such as learning, namely (1) to acquire *knowledge* and (2) to achieve *understanding* will be examined in the following two sections.

4.3.2 Visual representations and the varieties of knowledge

Concerning the epistemic functions of visual representations, the discussion hitherto has been about the possibility of gaining *propositional knowledge* via perceptually deciphering the encoded information. By analogical reasoning, my suggestion was that if it is an acceptable thesis that propositional knowledge can be gained via perception, then the same should be allowed for picture perception. This general statement was then limited by the addition of the following constraints.

Firstly, there are kinds of visual representations in science that presuppose more background knowledge than others in order to be interpreted correctly. The ability to decipher information presented in diagrams and graphs, for example, usually presupposes a certain training. In a similar fashion, Fleck has emphasised that observational skills in science relying on the use of instruments have to be learnt, that is, the students have to be trained how to 'see' correctly. In particular, he shows how a lack of training might contribute to misinterpretations of results in microscopy (see Fleck 1986b, 118ff.). In such instances, our perceptual abilities are not sufficient to gather all of the relevant information, as either the phenomenon or the form of its presentation does not belong to what we are evolutionarily familiar with to observe.[56] Here, testimony and perception are equally relevant to gather the information presented by those visual means. Such an interplay between different epistemic sources is not unusual – on the contrary, it seems to be common practice, as Scholz explains (Scholz 2009c).

The second constraint pointed out is closely connected to this co-operative outcome of epistemic sources. It seems that our perceptual apparatus yields propositional knowledge if we have learnt the relevant concepts beforehand. Thus, although our perceptual apparatus often allows us to navigate in the world without difficulty, we often need additional explanations to categorise phenomena correctly – that is, we need the relevant concepts that are often transferred via a combination of showing and telling, via perception and testimony. In the same way, a correct interpretation of certain images might presuppose the prior acquisition of relevant concepts.

Promising as the suggested capability to transmit propositional knowledge already sounds for the possible epistemic prospects to expect from the usage of visual representations in science, I wish nevertheless to examine another epistemic dimension of scientific images in this section. This additional epistemic potential of visual representations draws on two aspects discussed above, namely on the theory of dual coding and on the capacity to transmit non-conceptual content. The first point, put forward and empirically defended in the cognitive sciences, refers to the fact that the human brain can apparently store incoming information both visually and propositionally. Combining this with the thesis that picture perception can also transmit non-conceptual content, the theory of dual coding offers an explanation for why presenting information visually in the scientific discourse can constitute a proper epistemic merit. By using visual means, we can provide others with information, namely non-conceptual, that cannot be transferred otherwise. Moreover, as the theory of dual coding shows, our brain is apparently able to process visual information separately. Thus we are cognitively able to handle this information without translating it into propositionally structured expressions. The implications of this line of reasoning for acquiring the different types of knowledge analysed in epistemology will be discussed in what follows. Although philosophers are mainly concerned with propositional knowledge, i.e. *knowing-that*, there is nevertheless a variety of other epistemic concepts that has caught their attention. Grundmann mentions the following four kinds of knowledge in his introductory work to epistemology (see Grundmann 2008, 86):

1 propositional knowledge (knowing-that)
2 knowledge by acquaintance
3 phenomenal knowledge (knowledge about *qualia*)
4 knowing-how (skills)

Although there is this variety of different kinds of knowledge, Grundmann points out that epistemologists are primarily concerned with knowing-that (see ibid., 71). Eva-Maria Jung explains what reasons are commonly mentioned to justify this prioritisation. She identifies two different arguments put forward as a rejoinder to the claim that epistemologists wrongly focus on propositional knowledge (see Jung 2012, 13). Firstly, philosophers claim a difference in essence between knowing-that and knowing-how. And, as epistemology is exclusively concerned with propositional knowledge, knowing-how simply does not belong in the scope of its analysis. Secondly, knowing-how can be reduced to knowing-that. The former therefore need not be considered as an independent kind of knowledge.

Grundmann analyses different arguments to reduce knowledge of the kinds (2) to (4) of the list above to knowing-that (see Grundmann 2008, 74ff.). He comes to the cautiously formulated conclusion that it might be possible to reduce all of them to propositional knowledge (see ibid., 85). Moreover, he claims that even if such a reduction might not be possible, there are two good reasons[57] supporting the prioritisation of propositional knowledge in epistemology: (a) only propositional knowledge can be communicated and thus shared within a community; moreover, only propositional knowledge can be cognitively processed further via valid inferences, and (b) only propositional knowledge is in line with the aim of truth in epistemology (see ibid., 86).

Now, the above analysis provides argumentative means to broaden the focus of epistemology, as it permits calling into question at least one of the two reasons mentioned by Grundmann. It will be seen in due course that the claim about communicability can be easily rejected. In the same way, the results we hitherto obtained can be used to show that there are no particular difficulties in cognitively processing visual information.

In the following discussion, the focus will be primarily on *knowing-how*. This more detailed analysis will allow a brief comment on *knowledge by acquaintance* and *phenomenal knowledge*. All three concepts are related to learning and the sharing of knowledge more broadly in communicative contexts. However, it can be noted that, whereas knowing-how seems to be of special relevance for educational purposes, in science, and thus in relations between experts and laypeople, phenomenal knowledge might be of relevance to experts *per se*. If it can be shown that at least one of the kinds of knowledge mentioned above can be promoted via visual representations in science, their epistemic relevance – in comparison to linguistic representations – seems then to be proven.

The topic of *knowing-how* as an independent epistemic category, i.e. independent of propositional knowledge, is discussed broadly both in epistemology and in the philosophy of mind. To explain this concept, I will follow Eva-Maria Jung and Albert Newen's suggestion to draw a distinction between *theoretical* and *practical knowledge* (see Jung and Newen 2011, 95). This distinction is explained as follows:

> [t]heoretical knowledge […] describes a relation between a subject and a proposition thereby being related to a norm of truth. […] Practical knowledge, instead, describes a relation between a subject and an activity. This knowledge is related to the norm of success: We ascribe some ability to a person if she is able to successfully perform it.
>
> (Jung and Newen 2011, 95)

In addition to this, Jung and Newen point out that practical knowledge also implies a kind of warrant concerning the ability to perform the relevant action. This supplementary condition is necessary to exclude cases of performing some action x to bring about y that happen to be successful by mere chance. It would be counterintuitive to call such instances 'knowledge' (see ibid.).

According to this distinction, knowing-how belongs to the category of practical knowledge. As was highlighted in Grundmann's list of knowledge categories above, knowing-how is commonly regarded as consisting in certain skills. Knowing how to ride a bicycle or how to play the piano are common examples in philosophy. In science, we might think of instances such as knowing how to set up certain experiments, how to use instruments such as microscopes, or how to write a scientific article, etc. Including all kinds of accidentally successful action performances as instances of knowledge-how is inappropriate, as is subsuming all kinds of reflexes under this label. Therefore, Jung suggests as a criterion of demarcation that only actions brought about intentionally belong to the domain of practical knowledge. These intentional acts can be further characterised either by being directed at a particular aim or by certain formal aspects of how to perform the respective action (that is, a conformity to certain rules) (see Jung 2012, 158). Moreover, she claims that these intentional actions can be influenced by processes of learning and modification by the respective subject (see ibid., 159). If the student realises that a certain action does not lead to the intended aim, or only via a variety of unnecessary detours, she can learn to improve her actions (see ibid.).

Now, this characterisation of the object of knowing-how makes clear why the question dominating the respective debate in epistemology is about a possible reduction of knowing-how to knowing-that. If there are rules, say, about how to play the piano correctly, then why not argue that the relevant knowledge simply consists in *knowing that the piano is played in accordance with these rules*? In particular, philosophers convinced that propositional knowledge is the only category relevant to epistemological discussion suggest different strategies, for example, like the one drawing on rule-following just mentioned, to reduce knowing-how to knowing-that.[58] As Jung points out (see ibid., 13), these attempts enable them to maintain their project to exclusively analyse propositional knowledge without being forced to ignore the epistemic phenomenon of knowing-how.

Tempting as this strategy might seem, Jung also shows that there are at least two major difficulties that proponents of such reductive approaches have to face. On the one hand, they have to explain that, although an epistemic subject might know all the relevant rules about how to perform action x correctly, she is still not able to do so (the so-called 'knowledge-action-gap'). On the other hand, they have to account for the fact that there are actions which we perform to reach a goal that are not guided by rules (see ibid., 48). Jung takes these findings as important hints that although "practical knowledge might involve the knowledge of regulative propositions concerning the action", a complete reduction of knowing-how to propositional knowledge is not possible (Jung and Newen 2010, 124).

Contrary to such reductive approaches, she emphasises the relevance of knowing-how as an object of inquiry in epistemology in addition to propositional knowledge (see Jung 2012, ch. 1.5). She supports this initial conviction with further arguments bolstering the dichotomy between propositional and practical knowledge. Both with regard to contents transmitted and to the aims pursued by their means, the two kinds of knowledge differ essentially (see ibid., ch. 3.3). The following list summarises her theses on the topic.

- *Content*: the object of knowing-how are intentional actions. This kind of knowledge is always related to certain contexts and epistemic subjects. In this sense, the contents of knowing-how cannot be objectified completely, contrary to propositional knowledge, whose content is thus expressible by propositional means.
- *Aim*: the aim of knowing-how consists in successful action performances. Consequently, it can be assumed that the acquisition and deployment of knowing-how to perform such actions are guided by a particular norm, namely that of successful action performance (contrary to the norm of truth in the case of propositional knowledge).

I agree with Jung that knowing-how and knowing-that should be regarded as distinct categories in epistemology. Despite my general sympathy with her approach, two critical remarks have to be added about her criteria to characterise practical knowledge. Firstly, her thesis that the content of knowing-how cannot be objectified, i.e. that it necessarily contains subjective and private elements, does not seem to be convincing. In particular, there arises a certain tension to another claim of hers, namely that knowing-how can be taught, particularly by showing how to practice certain actions, and can thus be acquired in educational processes (see ibid., 72). If, however, teaching is possible in such a visual format – this issue will be returned to in due course – there have to be at least some paradigmatic instances of the action in question that can be demonstrated in order for it to be copied by the student. A partial objectification thus seems to be possible.

Secondly, although it seems to make sense to distinguish between propositional and practical knowledge along the lines of different norms, there remain some doubts about whether she has chosen the correct ones for her contrastive project. Especially regarding propositional knowledge, the debates in epistemology show that there is no consensus amongst philosophers concerning the status of truth. An example: Alvin I. Goldman, who proposes a "veritistic approach" in epistemology, that is, who emphasises the relevance of true belief as the predominant aim in our knowledge-seeking enterprises (see Goldman 1999, ch. 3), has been constantly criticised by others who object that he is wrong to put such a stress on truth alone. A similar objection might be raised to Jung's account if she claims truth to be the decisive criterion on the part of propositional knowledge in order to enable the relevant distinction between both knowledge categories.

Despite these critical remarks, however, Jung's argumentation seems to be quite convincing. Especially, the fact that her work is located at the interface between epistemology and the philosophy of mind allows her to elaborate another interesting thesis. In an earlier article, Jung and Newen had already pointed out that the constant misunderstandings of Gilbert Ryle's concept of knowing-how consist partly in neglecting the fact that his approach not only aims at a semantic analysis of the term, but also poses the question of "whether all mental cognitive processes can be analyzed in terms of propositional knowledge" (Jung and Newen 2011, 84f.). They argue that Ryle's project, which is embedded in the philosophy of mind, is also meant to tackle the topic of how knowledge is represented in the mind so that the latter can process it. Jung and Newen elaborate on this analysis of representational modes of knowledge in their own hypotheses about the distinction between propositional and practical knowledge.

They suggest three different modes of representation, namely "(i) propositional representations, (ii) sensorimotor representations and (iii) image-like representations" (ibid., 96). They characterise the first category as "language-like" (ibid.). Jung specifies this later as implying the ability to bear truth values and as being conceptual in kind (see Jung 2012, 164).

Contrary to this, the second category is considered as being non-conceptual in kind. Moreover, as Jung and Newen point out, the latter is also closely connected with certain qualities of our environment that we perceive and which trigger certain actions (see Jung and Newen 2011, 97). These representational means are deeply intertwined with our perceptual abilities. Jung explains that the human body is the object of sensorimotor representations. What is represented in the mind about a particular action are its expected duration, the kind and quantity of bodily forces to perform this action and certain motoric rules (see Jung 2012, 171). Although practical knowledge can entail rules that are expressible by linguistic means, and although the respective skills might at least partly be acquired by such propositional knowledge, Jung defends the claim that practical knowledge is usually represented in the sensorimotor way. She presents two aspects to support this claim: on the one hand, if the performance of certain skills is interrupted or disabled, for example because of certain diseases, we will note that we will not have recourse to propositional knowledge for guidance. On the contrary, attempts to consciously focus on the action in question will usually be experienced as disruptive rather than as helpful. On the other hand, Jung claims that small children and animals who do not possess a language are able to perform reasonable actions nonetheless and can thus be said to possess practical knowledge of certain kinds (see ibid., 177). Of course, assuming that knowing-how and knowing-that are represented differently in the human mind also lends further support to Jung's thesis that knowing-how and knowing-that are two independent epistemic categories.

Finally, Jung and Newen suggest a third category of mental representations, which they call "image-like". Contrary to sensorimotor representations, they are independent of concrete situations, as they can also be triggered by our imagination. Furthermore, they are "systematically connected with perceptual images and sensorimotor representations" and "with other image-like patterns" (Jung and Newen 2011, 98). The interesting thing about this third category that Jung highlights is the possibility of making use of image-like representations in educational contexts. She points out that, whereas sensorimotor representations cannot be consciously accessed, image-like ones can, and are thus employable as a medium to transfer the relevant knowledge for educational purposes (see Jung 2012, 180). To begin again with a critical comment on this: it does not quite convince that we cannot consciously access the sensorimotor representations of certain actions. From my point of view, it is exactly this that happens if people are asked to show or demonstrate the performance of certain skills. Admittedly, they will not consciously process all the details of this action, but they can call to mind the way they usually perform it in order to demonstrate it. This seems to suggest that they are at least aware of what is essential to this action to be demonstrated so that their students can copy them. Again, this line of reasoning is already implied in Jung's own work when she discusses Edward Craig's pragmatistic conception of knowledge. In this context, she highlights the fact that Craig's concept of the good informant, which Craig takes to lie at the heart of our ordinary concept of knowledge, not only entails classical testifiers but also people who can answer the question they were asked not by telling, but only by showing how to do something (see Jung 2012, 72).

Despite this critical remark, Jung makes a good point in arguing that image-like representations are particularly useful for educational purposes. Different components, already discussed above, play a role in this and now require piecing together.

A start can be made with what seems to be most beneficial when using visual representations for educational purposes: it is not only that we are able to make use of images to transfer practical knowledge at all – which is not possible with the aid of linguistic representations. It is apparently also the case that, from a methodological point of view, such an educational practice permits a considerable expansion in the size of the audience. Whereas a teacher can address only a limited number of students by a direct demonstration of a particular action, showing how to do x via images not only allows a broader audience to be reached on a synchronic level – for example, by live-streaming a lecture – but also diachronically, for example by means of images showing how to set up a particular experiment in a textbook.

After practising with the aid of such images, the students can make use of them for mental training, as Jung explains (see ibid., 181). 'Mental training' means that people are able to imagine certain actions and perform them mentally so that their actual performance of these actions will be later enhanced.

From an epistemological point of view, these features constitute proper epistemic merits. As explained above, knowing-how cannot be translated into linguistic expressions, that is, traditional methods of teaching are not possible. Showing people directly how to do x might be a way out of this dilemma, but it considerably restricts the number of people that can be addressed by this demonstration. A methodology of utilising images in this way not only permits the transfer of practical knowledge to be made public, but also enables teachers to professionalise it. As images, moving or non-moving, can be recorded and stored, these educational means are not only reusable in a variety of instances, they can also be subjected to performance ratings which might suggest modifications to the initial images in order to better meet the learners' requirements.

Of course, the issue discussed here has already acquired the utmost importance for people concerned with electronic learning and virtual reality. Max Hoffmann and his colleagues, for example, propose utilising virtual-reality tools in engineering studies (see Hoffmann et al. 2015). They claim that in this way more students can be given practical training, even though their universities might not be able to offer them the relevant training in a real laboratory because they lack the financial resources to do so. Thus, Hoffmann et al. point out another dimension in which to broaden the scope of practical training, namely via virtual-reality tools.

Finally, the whole process can also be reversed, that is, visual representations can be used to let experts learn about the implicit knowledge of practitioners. That such a kind of knowledge is often present and can play significant roles in cognitive processes has been pointed out by Eugene S. Ferguson who explains, for example, how non-conceptual thinking has guided the design and development of machines by craftsmen and designers (see Ferguson 1977). Now, as Hoffmann indicates,[59] by experiencing virtual-reality simulations, craftsmen or technicians might then be able to indicate why they think that certain newly developed machines do not fit their requirements, despite their lacking the conceptual ability to communicate this linguistically to engineers. The reasons that these epistemic merits are possible need recapitulating. Two aspects seem to be relevant: firstly, visual representations are cognitively accessed via perception. This enables the transmission of non-conceptual content. Secondly, Jung's discussion of different ways to represent knowledge in the human mind also makes plain why we can process information presented visually quite easily and without the necessity of translation. It simply matches the way we think about certain aspects of the world. Here we can link our considerations to some results from the cognitive sciences, namely to the theory of dual coding – a connection that is also suggested by Jung (see Jung 2012, 178). Proponents of this theory suggest that information is encoded in two different ways in the human mind, namely propositionally and visually. This hypothesis seems to be supported by empirical studies on certain brain lesions that disable one of the two possible ways to store information. An example are patients suffering from aphasia, that is, the loss of their ability to communicate linguistically,[60] who might nonetheless be able to communicate by visual means (see Sacks 2010, 45f.).

To summarise the results so far, visual representations can play an essential, even indispensable part in educational processes focusing on knowing-how. Consequently, we are entitled to maintain that some scientific images possess an epistemic status that is independent of other representational means and thus not epistemically reducible to them. Having discussed visual representations in the context of propositional and practical knowledge, another of their epistemic merits will now be examined that is connected with categories two and three of Grundmann's list above: *knowledge by acquaintance* and *phenomenal knowledge*.

What I am about to suggest is best grasped by starting with a negative point. It was explained above that the dual coding theory suggests two different ways of mentally processing and storing information: one dealing with propositional, the other one with visually presented information. Apparently the student's mind works best if both ways are activated during the process of learning (see Eitel and Scheiter 2015, 153). As Alexander Eitel and Katharina Scheiter argue from an educational-psychology point of view, this effect – also known as the "multimedia effect" – obtains not only when text and image are presented simultaneously to the student, but also when presented sequentially (see ibid., 154). However, what happens if one of these ways is completely omitted? More specifically, what happens if the student in question only receives propositional information about subject x and no visual clues, or vice versa, only visual ones but no propositional information? Does she nonetheless acquire a kind of knowledge in either of these cases? Regarding this question, it seems relevant to consider two aspects, namely the background knowledge of the particular student and her preferred style of learning. The latter refers to the fact that some people are more apt to process visual information than others, who prefer linguistic explanations (see e.g. Kirby, Moore and Schofield 1988).

To start with the presentation of mere visual information, it can be assumed that people with less background knowledge will have greater difficulty cognitively processing the information presented, and thus understanding what they are supposed to learn. A reference can be made here to what has already been said about image games: the student might be able to decipher what is shown in the image, but she might not at all understand what her teacher, by presenting this information, intends to tell her. As Kjørup has pointed out, most images are in need of linguistic anchoring in order to be useful in a communicative situation – such as in educational processes. The second case, that is the presentation of mere linguistic information, is illustrated by Wartenberg's example of guidebooks for bird-watchers. Suppose, for the sake of argument, that such guidebooks do not contain images but only linguistic descriptions and explanations. What kind of information will be lost in this scenario? What might be learnt from images, but not from the corresponding text? Suppose that you opened this somewhat informationally impoverished book on the page describing wrens. Suppose further that you have never seen a wren – neither in the wild or depicted in any way – before reading this entry. Now consider the following two questions: do you think that after reading the entry you would be able to recognise a wren if you saw it in the wild? Could you imagine its appearance? It can be assumed that you would not be able to do either of these. Of course, your background knowledge about other birds might help to exclude some completely odd mental images of a wren. For example, the entry tells you that it is smaller than the common house sparrow. Thus, it would be rather unlikely that you would imagine a bird the size of a dove after reading it. Nonetheless, the text alone will not provide you with the kind of information necessary to create a mental image of this bird. Images, on the other hand, can easily provide us with this kind of information. That is, *they can acquaint us with physical entities* of which we have no genuine experiences such as those gained by watching them in the wild or in a zoo.

This example thereby brings together aspects from both categories of knowledge, that is, knowledge by acquaintance and phenomenal knowledge, without completely agreeing with either so that we could adopt the respective label for the current case. Let me explain.

On the one hand, the above example apparently has a lot in common with Frank Jackson's famous *Mary argument* in the philosophy of mind. It reads as follows:

> Mary is confined to a black-and-white room, is educated through black-and-white books and through lectures relayed on black-and-white television. In this way she learns everything there is to know about the physical nature of the world. She knows all the physical facts about us and our environment, in a wide sense of 'physical' […]. If physicalism is true, she knows all there is to know. For to suppose otherwise is to suppose that there is more to know than every physical fact, and that is just what physicalism denies. […] It seems, however, that Mary does not know all there

> is to know. For when she is let out of the black-and-white room or given a color television, she will learn what it is like to see something red, say. This is rightly described as *learning* […]. Hence, physicalism is false.
>
> (Jackson 1986, 291, his italics)

There are similarities as well as dissimilarities to the bird-guide example. What is similar is the way Mary and the prospective bird-watcher learn about their subject matter first. Both of them get cognitive access in a somewhat limited way only. Mary has to learn about colours without ever experiencing one and, likewise, the prospective bird-watcher has to learn about wrens. Both of them lack certain qualitative information in what they learn about their subject matter. The difference between both examples is, of course, the object of learning. Jackson's argument is about *qualia* – i.e. the question *what it is like* to experience something, say, red, whereas the bird-watcher example is about physical objects in general.

I do not want to dwell on Jackson's argument, as my point is not about *qualia* and physicalism in the philosophy of mind.[61] Despite the difference in direction, Jackson's argument nevertheless makes it very plausible that, in some instances, linguistic descriptions alone will not suffice to provide us with the necessary information to construe a correct mental representation of the entity in question – neither of a certain colour nor of the appearance of a particular bird.[62] Images, however, often allow us to construct a mental representation without great effort. Such mental images can then be used, for instance, to recognise examples of the same species in the wild by comparing the mental image and the visual appearance of the bird in question. Yet because of the directional difference between Jackson's argument and the bird-watcher example, I am reluctant to call what has been learnt by the student about the visual appearance of the wren phenomenal knowledge.

Similar difficulties arise with regard to the second category, namely *knowledge by acquaintance*. Nonetheless, it can be assumed that it describes very well what happens cognitively when dealing with instances like the two examples just mentioned. Bertrand Russell, who introduced this concept in epistemology and compares it to what he calls "knowledge by description", defines it in the following way: "I say that I am acquainted with an object when I have a direct cognitive relation to that object, i.e. when I am directly aware of the object itself" (Russell 1910–1911, 108). Obviously, such a direct cognitive relation to the object in question is what is missing in the case of Mary and the prospective bird-watcher above. Neither of them has direct access to their object of interest, namely colours or wrens. This relational character of 'acquaintance', that is, the relation between the epistemic subject and the object in question, is particularly stressed by Russell as one of its constitutive characteristics (see ibid., 109).

Moreover, as Ali Hasan and Richard Fumerton point out, knowledge by acquaintance "is knowledge of something and logically independent of knowledge that something is so-and-so" (Hasan and Fumerton 2014, sect.

1). Summarising Russell's account, they add that "for Russell acquaintance is nonjudgemental or nonpropositional" (ibid.). These are the aspects of knowledge by acquaintance that shall be emphasised here. Apparently this conceptual framework fits well with what has hitherto been stated about the acquisition of non-conceptual content via perception – either in a direct way or mediated via visual representations – and its processing and storage in a separate cognitive subsystem, as indicated by proponents of the theory of dual coding.

Unfortunately, just as I cannot adopt the concept of phenomenal knowledge for my purposes, neither can I wholeheartedly subscribe to the theory of knowledge by acquaintance. The dispute is about the objects of these knowledge-relations. Russell suggests that "sense-data" should be regarded as the paradigmatic instance of objects of acquaintance (see Russell 1910–1911, 109). He explains: "[w]e shall say that we have acquaintance with anything of which we are directly aware, without the intermediary of any process of inference or any knowledge of truths" (Russell 1912, ch. 5).

Yet I am reluctant to commit my approach to the sense-datum theory because this account entails many well-known problems.[63] According to this theory, for example, sense-data are solely bound to private subjective experiences, which leaves unresolved the question of whether we can ever know that we are talking about the same objects if they are given to us in this private and subjective way (see Grundmann 2008, 475), despite the fact that people have no particular difficulty in agreeing about what they perceive, for example how many chairs and tables they see in a particular room. Thus, there has to be an object of reference that guarantees this inter-subjective agreement on the facts. Hence, an account of knowledge by acquaintance that focuses on sense-data as an appropriate epistemology cannot be adopted here.

At first sight this might be a rather unsatisfying result, as neither of the two approaches can be accepted as the proper epistemic framework for the purpose of explaining what kinds of knowledge are transmitted via images. However, neither the theory of phenomenal knowledge nor the account of knowledge by acquaintance was designed for this purpose, and consequently criticising them for not accounting for this phenomenon is inappropriate. However, this discussion was not intended as a critique. On the contrary, the above has shown in what sense both accounts might, despite those difficulties, contribute to a better theoretical understanding of how it is possible to acquire information relevant to constructing a mental image of the entity in question. Images can transmit a non-propositional content. In some instances, this content entails that all relevant information constructs a corresponding mental image. Both theoretical approaches, dealing with questions about either phenomenal knowledge and knowledge by acquaintance, support the thesis that there is more to human cognition than mere propositional knowledge. They suggest models for how to comprehend the acquisition of non-propositional knowledge. Consequently, the proposal is to take those approaches as a starting point to develop a proper epistemological account concerning information distribution and acquisition by means of images. To be concise, visual representations are relevant in scientific discourse as they can be used to convey a mental presentation of the appearance of the entity depicted. They can, so to speak, foster an inner picture of it by transmitting non-conceptual information that is processed in a separate cognitive subsystem. This information will, however, be lost if scientific images are replaced by mere verbal descriptions.

In order to elucidate the role of imagination in science, Tamar Szabó Gendler's discussion of the intimate connection between imagination and counterfactual reasoning should be taken into account (see Gendler 2013, ch. 4.4). "It has been argued that imagination plays a central role in figuring out what would happen – or what would have happened – had things been different from how they in fact are or were" (ibid.). If we can assume that there is such a connection, the role of imagination in science becomes obvious at once. *Counterfactual reasoning* is a main feature of the scientific enterprise itself. It is needed to invent and perform experiments, to invent theories and ways of testing them. Furthermore, it is a basic requirement that natural laws permit counterfactual reasoning within their scope, that is, they have to remain valid under altered circumstances. Predictions can be given in the form of counterfactual statements, for example. In all of these contexts and scientific tasks, imagination plays an important role, and so does the knowledge conveyed by visual representations concerning their object of depiction.

Thus, the capacity to transmit non-conceptual content and to make it directly accessible via perception allows us to explain in what sense visual representations can contribute to the acquisition of practical knowledge and how they can acquaint us with entities so that we acquire mental images of them. Beyond that, the fact that we cognitively access visual information by perceptual means explains in what sense images can contribute to another epistemic desideratum, namely to *scientific understanding*. This is what we will discuss in the next section.

4.3.3 Visual representations and scientific understanding

Apart from the acquisition of (propositional) knowledge, learning is normally associated with the aim of understanding. Peter Kosso points out that solely memorising propositions is not what is expected of our students – especially not in science (see Kosso 2007, 175); they are not usually required to parrot hypotheses and statements during an examination, for example. On the contrary, scientific training ideally means having students partake in the community of researchers, that is, enabling them to apply acquired knowledge to new questions, to reflect critically on this information and, if necessary, to correct some of its components. The aspect of understanding now acquires relevance here. Are there any particular contributions, then, that visual representations can make with respect to scientific understanding? Possible answers to this question will be presented following a brief discourse of this incipient point on the epistemic relevance of understanding itself.

Scientific understanding is commonly regarded as an ability to coherently fit new items into one's knowledge system and to apply the newly acquired information to solve further tasks and puzzles. Wesley C. Salmon phrases this in the following way: "[…] we have scientific understanding of phenomena when we can fit them into the general scheme of things, that is, into the scientific world-picture" (Salmon 1993, 12f.). But how exactly should this fitting-relation be conceived? What does Salmon suggest when he claims that 'to understand something' means 'being able to fit it into "the general scheme of things"'? An answer to this question is offered by Jonathan L. Kvanvig who emphasises that this fitting-relation is the crucial difference between *knowledge* and *understanding*. He states:

> […] that understanding requires, and knowledge does not, an internal grasping or appreciation of how the various elements in a body of information are related to each other in terms of *explanatory, logical, probabilistic, and other kinds of relations that coherentists have thought constitutive of justification.*
>
> (Kvanvig 2003, 192f., my italics)

In a similar fashion, Kosso suggests that understanding in science goes beyond a mere additive compilation of evidence on a certain matter (see Kosso 2007, 179). That there is something important lacking in cases when evidential facts are collected in science without the achievement of understanding is highlighted by several examples. For instance, he draws his readers' attention to how the phenomenon of contagion was discovered (see ibid., 182) and points out that, although Thucydides in ancient Greece reported in detail how people became infected with the plague through nursing patients already sick, he did not infer the mechanism of contagion lurking in the background. As Kosso puts it:

> [h]is knowledge, however, stops with the isolated fact of the disease somehow being transmitted from one person to another. […] He is not credited with the first proposal of the germ theory, since he did not understand the process of infection.
>
> (Kosso 2007, 183)

It is in this sense that Kosso claims that scientific observation alone might yield factual knowledge but not understanding (see ibid., 184). Taking the above discussion into account, this statement seems surprising – but only at first sight. Two clarifying remarks should be added at this juncture.

Firstly, Kosso's thesis that observation – respectively (visual and pictorial) perception – can yield propositional knowledge if concepts are available is acceptable, and yet (secondly) his statement is still puzzling in that the way he phrases his ideas about scientific observation seems to suggest that the latter is more or less independent of theoretical considerations which, of course, it is not. Elsewhere, he has discussed in detail the intertwining of observation and scientific theories (see e.g. Kosso 1988; 1993). Thus, to understand his claim correctly, we might interpret him in the following way: observation is theory-related in different ways. Yet it might be the case that the theories used are not adequately embedded within the broader network of scientific theories that he calls attention to. If this happens – either by deliberately screening off other theoretical assumptions that might lead to a rejection of the theory at hand or unwittingly as a consequence of the observer's own scientific training, a proper understanding of the phenomenon at hand will be blocked as in the Thucydides example above.

However, even though I agree with Kosso's suggestion, another constraint to his thesis should be added, namely that understanding is usually a gradual matter. This assumption seems to be perfectly in line with Kosso's ideas. If less background knowledge is available that the scientist can use to interpret her observations, her understanding of the phenomenon at hand will also be affected in a negative way. It can be stated, then, that Thucydides did understand that the disease observed was transmitted from person to person, but he did not understand how this happened. Consequently, his understanding of disease transmission was only partial, and not, as Kosso suggests, completely lacking.

The topic of understanding has rather recently started to attract the attention of epistemologists. This new focus of research is an aftermath of the challenge posed by the Gettier-cases concerning the analysis of knowledge. One consequence of this discussion has been to bring into focus the epistemic aims and values a subject might pursue when seeking knowledge (see Jung 2012, ch. 2.4.3). It is here that the debate about understanding as an epistemic desideratum valuable in its own right begins (see Pritchard and Turri 2014, sect. 5). Moreover, it is also here that we get a clearer grasp of what motivates Kosso's critique on regarding the striving for evidence as the correct aim of science. Philosophers concerned with the topic of understanding usually point out that *truth* is but one aim valued in epistemic projects. Thus, amassing true beliefs might be a laudable facet of science, but does not reveal its whole epistemic enterprise.

In particular, this debate has been fuelled by Kvanvig's work (see Kvanvig 2003). He discusses the question of whether understanding is a species of knowledge. Kvanvig starts his analysis by pointing out that it is commonly assumed that understanding and knowledge are closely connected (see ibid., 188). It is usually said that if a student understands that x, she also knows that x. In instances like this, the student will possess true beliefs that are propositionally structured if she understands the respective information. In this sense, propositions can also play a role. This assumed intimate connection between knowledge and understanding is now challenged by epistemologists, some of whom even call for a replacement of 'knowledge' by 'understanding' in epistemology as a consequence of this critical discussion.[64]

What is at stake here is the *factivity* of understanding. What does this mean? Obviously, we can have knowledge without understanding (see ibid., 191), as the above example of the student learning by rote shows. But does this claim also hold the other way around, i.e. do we need knowledge as a basis for understanding? Usually it is admitted that there are factive and non-factive usages of the term 'understanding'. Factive understanding implies truth in the same way that knowledge does, as Kvanvig points out (see ibid., 190). Non-factive understanding, then, is either due to "misspeaking or to the expression of propositions that do not involve the concepts of knowledge or understanding central to epistemological inquiry" (ibid.). Statements such as, 'I understand that he was not able to attend the conference', illustrate this latter case.

However, non-factive understanding is often more or less immediately ruled out as a candidate for epistemological investigations, which is Kvanvig's line of argument (see ibid., 190f.). He explicitly draws our attention to factive understanding and identifies two kinds, namely:

> propositional understanding and objectual understanding. The propositional sort occurs when we attribute understanding in the form of a propositional operator, as in understanding that something is the case, and the objectual sort occurs when understanding grammatically is followed by an object […]
>
> (Kvanvig 2003, 191)

Although the second sort is not straightforwardly propositional in kind, he also thinks that it is factive, as we have to have true beliefs about the object in question in order to be attributed with an understanding of that very object (see ibid.). Moreover, Kvanvig argues that other varieties of understanding – such as "understanding why, when, where, and what are explicable in terms of understanding that something is the case" (ibid., 189). He does not consider understanding-how as a relevant concept in epistemology – similar to what was noted above about the concept of knowing-how – as it is patently more closely related to practical concerns than to theoretical ones (see ibid., 190).

The feature of factivity seems to suggest that understanding and knowledge are somehow on a par, that is, from an epistemological point of view, understanding does not seem to contribute anything new. If I know that Pluto has five satellites, I do understand that Pluto has five satellites. Both – knowing that p and understanding that p – presuppose that p is true, as Kvanvig makes clear. Despite this initial similarity, however, he defends the claim that there is also an important distinction, namely:

> […] once we move past its factivity [of understanding, N.M.], the grasping of relations between items of information is central to the nature of

> understanding. By contrast, when we move past the factivity of knowledge, the central features involve nonaccidential connections between mind and world.
>
> (Kvanvig 2003, 197)

Thus, from Kvanvig's point of view, understanding is independently epistemologically valuable because it involves the grasping of coherence relations amongst different true beliefs, and this grasping also contributes to the systematising and organising of our belief system (see ibid., 202).

Other philosophers defend conceptions of understanding that diverge even more radically from the concept of knowledge than Kvanvig's claims suggest. In particular, many scholars are less convinced of the factive status of understanding. Catherine Z. Elgin, for example, discusses understanding, amongst other things, in the context of scientific endeavour, and points out that it would not make much sense to demand factivity in this setting.

> The growth of understanding often involves a trajectory from beliefs that, although strictly false, are in the right general neighborhood to beliefs that are closer to the truth. The sequence may terminate in true beliefs. But even the earlier steps in the sequence should fall within the ambit of epistemology. For they are, to an extent – often to a considerable extent – cognitively valuable.
>
> (Elgin 2007, 37)

Her finding can be read both diachronically and synchronically. Diachronically, this affects the phenomenon of progress in science in general. Scientific realists point out that our current scientific theories are at least approximately true, and hence that we can think of the history of science as a developmental process towards truth. Of course, scientists might have deviated somewhat in the past (the phlogiston theory, for example), but nonetheless our theories and thus our knowledge of the phenomena, and also our understanding of them, has more or less constantly increased. Insisting on the factivity of understanding, that is, maintaining that understanding that p implies that p is true, would then expel such approximations to truth from the scope of 'understanding' completely, which would be a rather counterintuitive consequence.

A similar case can be made for the synchronic level in science. What is critically discussed here by philosophers is the usage of *idealisations* in cognitive processes in science (see e.g. Elgin 2007; Mizrahi 2012). Idealisations are, for example, brought about by laboratory conditions relevant to most experiments yielding observational data. Moreover, they also obtain due to making use of models or *ceteris paribus* laws in processes of reasoning. Therefore, idealisations are often the starting point for cognitive processes in science, though they are, strictly speaking, not true. They are simplifications of actual phenomena or processes. Particular aspects are intentionally omitted in these cases so that the amount of information is reduced. Can we nonetheless understand the (actual) phenomenon or subject matter in question? Our intuitions suggest that at least a partial understanding is possible, but a theory demanding the factivity of this cognitive achievement would deny this.

A corollary of what has been stated so far about the concept of understanding and its potential relation to factivity is that either we have to admit that images can yield propositional knowledge to be understood in an epistemologically relevant sense or that they simply do not belong to the scope of 'understanding'. Again, this seems to be a rather counterintuitive consequence of such an approach to 'understanding'. In this context, Elgin is correct in reminding us that "[w]e also understand pictures, words, equations, and diagrams. Ordinarily these are not isolated accomplishments; they coalesce into an understanding of a subject, discipline, or field of study" (Elgin 1993, 14). Although content with Elgin's statement that we use the term 'understanding' also with respect to those different vehicles of information, I suggest some clarifying remarks at this point. Earlier in this analysis, Scholz's suggestion was introduced that there is a variety of levels involved when speaking about 'understanding a picture' (see Scholz 1993). Bearing this in mind, we should at least make a distinction between the two levels of understanding implied in Elgin's quotation. On the one hand, we understand the respective vehicle of information (which might imply a variety of sub-levels of understanding, as pointed out by Scholz) and on the other, we understand the contribution that the content of this informational vehicle makes concerning the development of a theory or even, as Elgin states, "a subject, discipline, or field of study".

Anyway, both dimensions of understanding share the same difficulty if we focus on visual representations as the respective informational vehicles and nonetheless strive to maintain the claim about the factivity of understanding. As Elgin points out, images are not propositionally structured, and thus lack the capacity to bear truth values in the traditional Fregean sense (see Elgin 1993, 27). This provides an interesting twist to the starting point of processes of understanding. In the case of idealisations in science, the initial step consists in propositional statements that cannot be called 'true' in the strict sense, since they entail simplifications, etc. Visual representations, at least from the traditional point of view, are neither true nor false – nonetheless, as Elgin pointed out above, they can constitute the starting point for a process of understanding.

The thesis is, then, that by contributing to our understanding of scientific phenomena, visual representations fulfil an important epistemic task. Focusing on 'understanding' instead of 'knowledge' regarding the epistemic capacities of images in science allows us to support the claim that visual representations can play crucial roles in cognitive processes in this context by another argument. This line of reasoning runs as follows.

Visual representations are correctly taken as *heuristic tools* in this context, namely in the sense of supporting the cognitive process of learning. Yet, not only do they enable students to acquire propositional knowledge, but they also allow them to achieve an understanding of the information presented. Acknowledging the fact that understanding is an epistemic desideratum in its own right now enables a particular twist in the argumentation: whereas pointing to the heuristic function of visualisations usually implies the devaluation of their epistemic status, we can defend the opposite point of view. *If visual representations can facilitate understanding, and understanding is independently epistemically worthwhile, then it can be stated that images can make a substantial epistemic contribution.*

However, this line of reasoning presupposes (1) that understanding is epistemically worthwhile in its own right. So far, we have only pointed out that it is a distinct epistemic desideratum – but why should we strive for understanding? (2) We also have to show how visual representations can support scientific understanding. That they apparently do play an important role here is empirically supported by different studies carried out by educational psychologists (see e.g. Müller et al. 2012; Schnotz 2002; Vekiri 2002). Yet the question remains how it works. How exactly do images support scientific understanding? The remaining part of this section is devoted to answering these two questions.

The above examples of learning processes demonstrate that understanding adds an important epistemic dimension to our knowledge-seeking enterprises, and thus that epistemologists are well-advised to consider more seriously understanding as an epistemic desideratum in its own right. However, I do not agree with the broader thesis that the concept of knowledge should be replaced by 'understanding' in epistemology, because, although usually intimately linked, they are nonetheless quite independent of each other. As a corollary of this relationship, both concepts are relevant to consider when theorising about epistemic achievements, projects and practices. A start can thus be made by explaining what exactly understanding can add to the epistemic project in science.

Philosophers who consider understanding as relevant to epistemology commonly stress its additionally epistemic value which is spelled out in the grasping of certain connections in a body of information. Kosso expresses this benefit in the following way: "[u]nderstanding reveals the larger landscape and includes the ability to apply one idea to other situations without being given detailed instructions" (Kosso 2007, 176).

Here, Kosso points out two particular achievements of understanding: firstly, what he calls *revealing the larger landscape*, that is, understanding how bits of information in one's area of research fit together. For example, students in the philosophy of science might learn about Karl Popper's account on falsification first, and afterwards about Kuhn's theory of scientific revolutions. Learning in addition that these are successive approaches to explain (amongst other things) what demarcates science from pseudoscience will allow students to understand the sequential development of these theories much better, namely as a consequence of a shift in focus on the topic amongst philosophers of science. The second achievement of understanding that Kosso points out is that it enables scientists to apply their knowledge to answer new questions in their field of expertise. In this sense, understanding is an important goal of scientific education because, in the long run, it will enable students to do their own research.

From Kosso's perspective, this second epistemic accomplishment of understanding in science is a direct consequence of the first, that is, the understanding of connections (see ibid., 182). Earlier in this section, we mentioned Kvanvig's theses concerning the different kinds of relations possible here. Yet what *relata* do they connect? Here, Kvanvig only speaks vaguely about "various elements in a body of information" (Kvanvig 2003, 192). Does Kosso offer a more precise account in the context of science? He suggests that "[t]he achievement of understanding is in apprehending the connections between theories and the global coherence among concepts" (Kosso 2007, 179). Thus, the *relata* that he points out are, on the one hand, theories and, on the other, concepts.

Admittedly, understanding can be addressed as a particular phenomenon in both instances. However, clarifying the exact nature of the *relata* in question also depends on the degree of understanding that the recipient is supposed to acquire. It apparently makes a difference, for example, in the context of education whether students are required to understand a particular law and its applications or to grasp developments in the theoretical descriptions of a phenomenon. In particular, it is not always a set of theories that is linked in cases where understanding is attributed. Nevertheless, it can be taken that understanding is particularly valuable as it is based on realising the connections between, for instance, theoretical statements. One of the epistemic benefits that such a kind of understanding implies, without going into detail, is that it allows scientists to explain new phenomena by using metaphors[65] – which is also pointed out by Fleck. He explains how the invention of metaphors is made possible by the scientist's simultaneous membership of different thought collectives. More precisely, Fleck defends the claim that such a metaphoric reasoning is possible by making use of background knowledge taken from popular science (see Fleck 1979, 112).[66] The scientist is enabled to make this explanatory transition just by noticing the connection between two concepts or two theoretical approaches. Moreover, by introducing metaphors in scientific discourse we not only get epistemic access to a phenomenon that previously was not conceptualised at all, but it might also become the seed of a completely new theory. Here, the epistemic relevance of understanding becomes more than obvious. Now, in what sense can we state that visual representations support such understanding in science?

To answer this question it is appropriate to refer back to the results of educational psychology which explicitly deal with the contributions of visual representations in the context of learning. To summarise the results of the above discussion, those approaches suggested the following three ways in which visual representations influence the process of learning and how they can thus enhance understanding:

1 *Levels of information*: visual representations are not only able to transmit information about particular items, but also about relations among them.
2 *Visual deciphering*: visual information is predominantly grasped by making use of our perceptual apparatus. For example, comparative tasks amongst visually presented items can be performed in this way without the need to engage in long interpretations. Just by looking at a bar graph, the student may *simply see* the difference in length expressing a difference in quantity, etc.
3 *Cognitive processing*: visual information can not only reduce the cognitive load on the working memory, but also allows for a more economic handling of our cognitive resources in general.

In the following, we have to analyse in what sense these epistemic virtues can not only support learning in general, but also understanding in science in particular.

The first point seems to be obvious. It was said that scientific understanding is about grasping connections – especially relations between concepts, theories and the like. As Kosso puts it: "[u]nderstanding […] is entirely a matter of fitting into a pattern. Understanding depends on coherence" (Kosso 2007, 181). The patterns that Kosso mentions here can thereby appear on different levels. They can link individual concepts or statements, or individual concepts and theories, or theories to theories. Such patterns can support inductive and deductive reasoning, as they might, for instance, reveal relations of entailment or hierarchy. Moreover, those patterns can also link unknown items to already known ones – which seems to be the case that Kosso has in mind when talking about scientific understanding.

Now, visual representations can serve exactly this purpose. As Matthew T. McCrudden and David N. Rapp point out with respect to image design for educational purposes: "[a]n effective visual display as designed for educational purposes has two main functions: (1) to communicate important information and (2) to communicate relations about information via spatial arrangements" (McCrudden and Rapp 2015, online first). Thus, the obvious part to be played by visual representations is to show the connections mentioned by Kosso, i.e. to *literally visualise* them. Tree diagrams are a striking example in this context. Students are not only expected to learn something about particular items, but also about their relations. Visualisations can highlight such relations in an immediate fashion, and thus support the cognitive process of understanding.

McCrudden and Rapp discuss this contribution of visual representations to the epistemic processes of students' education under the labels of "organization" and "integration". The organisation of information in a given image can be accomplished at different levels, and thus allows the learner to draw relevant inferences. The authors mention three kinds in particular, namely "temporal inference", "hierarchical inference" and "relational inference". The sequential depictions in Figure 3.3, for instance, will allow the learner to draw temporal inferences about the life cycle of a frog. The tree diagram mentioned in the previous example can allow for hierarchical inferences between concepts. And the diagrams of the detection of gravitational waves, discussed in the introduction to this book (see Figure 1.2), can illustrate the last kind of inference. Those diagrams allow the recipient to compare the two recorded signals to each other and to the curve theoretically predicted for such events.

In addition to those inferences, mentioned by McCrudden and Rapp, there are a variety of spatial relations among objects that a recipient can infer by regarding images. The *Pioneer plaque* (see Figure 2.10) can illustrate this. The depiction at the bottom shows the place of the spacecraft's origin, and thus how it is related to our solar system.

Integration is closely related to organisation. McCrudden and Rapp point out that what is implied here is the relation between newly presented items and the students' background knowledge. This seems to be exactly what Kosso suggests for the case of understanding, namely to connect theories, i.e. newly learnt ones to formerly acquired ones. Now, how can visual representations facilitate this epistemic achievement? McCrudden and Rapp explain that there are two ways in which integration can take place: an active and a passive one. In particular, the second one offers an explanation of how images can serve the purpose at hand. They can entail clues that will (or, in the case of education, are supposed to) activate the students' prior knowledge. Active integration, on the other hand, is guided by the student's expectation. That is, the learner assumes that the visually presented information is somehow related to a field of prior acquired knowledge.

Although McCrudden and Rapp have a point in highlighting the fact that visual representations can contribute both to the organisation and the integration of information in the processes of learning, it seems that the latter, i.e. supporting integration, is not a special achievement of visual representations in particular, but can be gained by other representational means as well.

It might be objected that the epistemic achievements just explained are only of a secondary quality, as they are intentionally brought about by the teacher who utilises the visual representation and thus presents the information depicted in a way that the above-mentioned advantages of organisation and integration can be exploited. Visual representations contribute to understanding, but only in the context of previously known facts. Hence, they cannot make contributions to constituting a genuinely new kind of knowledge and understanding, but are only vehicles that pass on known information.

We have to admit that images can be used in this way, which holds, incidentally, for all other kinds of representational tools as well. However, we do not have to agree with the thesis that this is the only way that images can make contributions to epistemic processes and to understanding in particular. The rationale for this claim is closely connected to the second aspect concerning how images can facilitate learning, namely *visual deciphering*. This perceptual mode of access also enables recipients to make use of correlated skills that have developed in the course of evolution. In accordance with this, Zachary C. Irving argues for a fundamental role of visual representations concerning scientific understanding (see Irving 2011). He discusses the difference between visual and numerical representations and highlights the fact that, because of the limitations of human cognitive capacities, the former are particularly useful for the understanding of large data sets. His primary example concerns scatter plots which, according to Irving, are especially useful for detecting patterns among the data (see ibid., 780f.). As an example let us take a look at the Hertzsprung-Russell diagram (see Figure 4.5), showing the correlation between the temperature and magnitude of stars. Obviously, by simply looking at the plot, we can literally see how magnitudes, temperatures and luminosities of stars are related and which of these relations are the most common.

I agree with Irving that some visual representations are especially valuable as they enable pattern detection among data. However, this merit should be related to our abilities as visual observers and our resulting cognitive set-up, but I am reluctant to discuss this as a kind of cognitive limitation. That

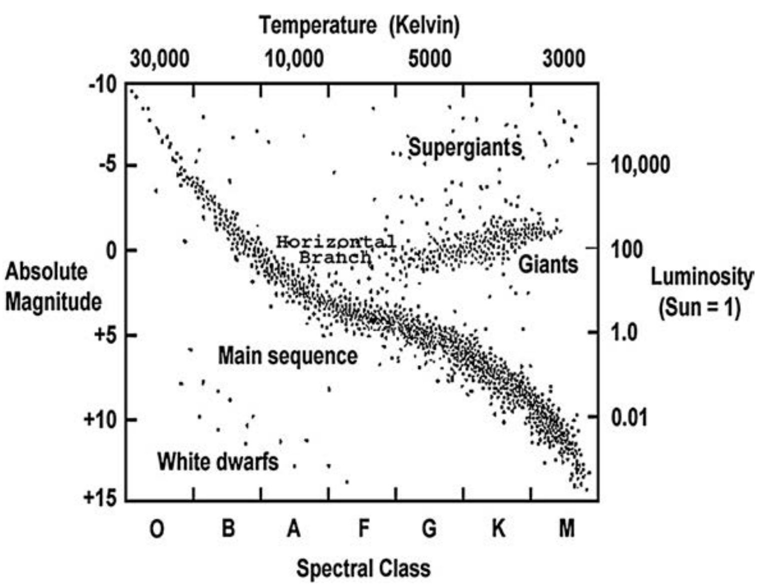

Figure 4.5 Hertzsprung-Russell (H-R) diagram.
Source: NASA/CXC/SAO.

human observers are particularly apt to perform this task is, for example, suggested by projects such as *Galaxy Zoo*. Such projects demonstrate, contrary to Irving's example, that human observers can detect patterns whose identification is simply not possible at the level of numerical data. That human beings are particularly skilled in the task of pattern detection is undoubtedly a consequence of evolutionary processes. Thus, making information available in a way that also activates these skills can enhance our understanding by connecting the cognitive processing of information to these abilities.

Consequently, the grasping of connections is not necessarily a result of a previously intended design. Contrary to such a sceptical approach, it can be assumed that not all relations detected with the aid of visual representations are previously known and this is because of the excellence of human observers in pattern detection. The capacity also to transmit non-conceptual information via images can contribute to such visual discoveries or detections of anomalies.

The final point concerning the ability of visual representations to enhance understanding is related to the aspect of *cognitive processing*. As McCrudden and Rapp explain, "[l]earners have limited processing resources. Of particular relevance to visual displays are the resources associated with attention and working memory" (see McCrudden and Rapp 2015, online first). What is important here is a more economic handling of those cognitive resources necessary for processing incoming information. Educational psychologists suggest that visualisations can constitute a kind of relief for our cognitive system which is achieved as follows.

On the one hand, visually presented information can guide our attention, as McCrudden and Rapp point out. In particular, by making use of 'signalling' techniques, important information can be highlighted in an image and the learner's attention can be directed towards it. The diagram of the yearly average number of sunspots is a good example (see Figure 4.6). An arrow has

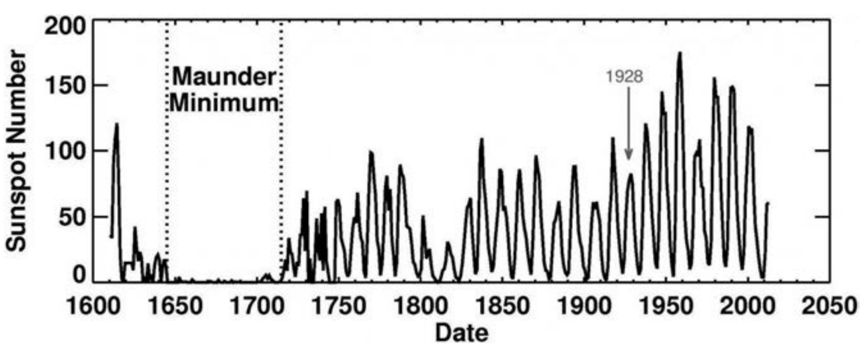

Figure 4.6 Diagram: sunspots.

Source: NASA. For a colour version of this image see www.nasa.gov/images/content/352130main_ssn_yearly_lg.jpg been added to indicate the peak of 1928 that researchers considered being similar to the emerging cycle of sunspots in 2009. This signal directs the viewer's attention directly to the relevant information.

On the other hand, and more importantly, visual representations can keep information and relations among the data available while we think about problem solutions. We do not have to store all the information in our working memory during this process.[67] In this sense, visualisations might provide the necessary cognitive resources to work out the relevant connections in order to fully understand a particular topic. This method of supporting the cognitive processing of information by visual representations is, for example, highlighted by McCrudden and Rapp. They explain that images can, for instance, reduce the effort needed to select important information, as they include signals which make this information more salient. "Similarly, a display improves processing efficiency, when it helps a learner organize important information more quickly with the display than in its absence or if the display is not designed well (e.g., related ideas are not near one another)" (McCrudden and Rapp 2015, online first). All of these aspects of information transmission with the aid of visual representations can enhance scientific understanding – also without a prior translation into propositional statements. The discussion above has made clear *how images can facilitate scientific understanding*. Our analysis has made plain that images often provide more efficient ways to achieve understanding than other representational means, for example, by visually organising the relevant information and by literally keeping it before the recipients' eyes. However, although our previous results do support the thesis that visual representations can play positive epistemic roles by facilitating scientific understanding, they leave open the question of whether there are instances that inevitably call for the utilisation of images to allow students to understand what has been presented. Or to put it differently, do we have to admit that there are always other ways to achieve scientific understanding that work equally well?

There are different answers to this question. Firstly, as has been pointed out by educational psychologists, there are different types of students. Some prefer verbal descriptions, whereas others rely on visual representations. Thus, a moderate thesis would be to claim that the latter type of learners are somehow in need of images to get a clear grasp of what they are supposed to learn.

The phenomenon of visual thinking has been discussed in section 3.1.1 and the suggestion made that images can play essential roles as tools of thinking in the exploratory context of science. As an example, Dr John Snow's discovery of cholera transmission routes was analysed. This discovery was made possible by his working with different maps arranging various facts that could offer a possible explanation for the spreading of cholera among the local population. Here it became clear that it was by working with those maps (see Figure 3.1) that Snow finally understood how the disease was transmitted. Barbara Tversky highlights this capacity of visual representations as tools of thinking. She discusses Snow's case and points out that it is often the case that "[i]n science […] the underlying phenomena generating the data are not always known" (Tversky 2015, 111). This was patently the case when Snow worked out his hypothesis by using maps.

On a more general level, Tversky claims that it is often due to the ambiguity of visual representations that they are such an effective means to develop problem solutions. She states that "[m]essy diagrams, then, can be crucial for thinking through problems, arousing and considering multiple possibilities. […] Because ambiguity allows reconfiguration and reinterpretation, ambiguous sketches promote discoveries and inferences" (ibid.). Thus, what is commonly regarded as a shortcoming of visual representations, namely their apparent ambiguity, turns out to be particularly advantageous in the context of visual thinking.[68]

Cases of visual thinking, then, suggest clear instances where images are inevitable tools to achieve understanding. Yet this doesn't imply that images are indispensable in processes of achieving understanding more generally. It seems to be a mere contingent fact about the make-up of the reasoners' minds that they rely on images in their cognitive processes.

Secondly, there are cases where images are indeed indispensable to scientific understanding because they transmit information that cannot be expressed otherwise. At least some images are capable of transmitting non-propositional content, such as micrographs or depictions in guidebooks in biology. If this information is essential to understand the phenomenon at hand correctly, for example how to discern between different birds of prey during their flight, it seems that images providing this information can be called indispensable to the respective process of understanding. The example afforded by Perini is pertinent here. She points out that electron micrographs can "represent very complicated structural properties, even when there are no linguistic terms for the same features" (Perini 2005c, 921). That is, if the structures visible in such a micrograph are to be communicated, the utilisation of the image clearly becomes necessary since there are no proper terms available to translate those features. Moreover, if this communicative exchange finally leads to an understanding of the reasons for the functions of those structures, it becomes clear in what sense certain images can indeed be indispensable to the process of achieving scientific understanding.

As a concluding remark, we will discuss an objection to this claim put forward by Henk W. de Regt (see de Regt 2014). He agrees with the general idea that visual representations can facilitate scientific understanding. However, de Regt also claims that "visualization is a very effective way to achieve scientific understanding but it is *not* indispensable – there are other ways to reach the same goal" (ibid., 378, my italics). From his point of view, visualisability constitutes a theoretical quality that can unfold only in combination with particular skills of the working scientists (see ibid., 380). Moreover, the acquisition of these skills is part of educational processes within a particular community (see ibid., 393f.). In this sense, it is not a merely subjective characteristic of understanding but shared by members of a group. However, as a consequence of the necessity to learn depictive conventions beforehand, some scientists will not be able to profit from certain visualisations when trying to understand certain phenomena. They simply do not possess the relevant background knowledge to interpret them correctly, whereas others equipped with this information will benefit from the visual representation at hand. To illustrate his thesis, de Regt discusses the case of Feynman diagrams in physics (see ibid., 389ff.).

The educational process that de Regt mentions in this context coincides with Fleck's (and also Kuhn's, as de Regt mentions (see ibid., 394)) ideas about scientific education. His approach is similar to theirs in that he also discusses the necessity to work with experienced scientists or practitioners to learn to see correctly, i.e. to make correct observations in their scientific fields (see Fleck 1979, 54, 104; Fleck 1986b, 118).

De Regt is clearly right in pointing out that not all kinds of visual representations are equally intelligible to the human mind. The theory of image games allows us to acknowledge this fact without great difficulty. As there are varied people and varied intentions involved in such games, a layering of meanings can occur when visual representations are used in communicative contexts. To understand those image games correctly, we then have to have the relevant background knowledge about the contexts in which those images are used.

Moreover, it can be agreed that, as tools of communication, visual representations have been developed in the course of their application, and thus have been adapted to particular requirements of information transmission – just as it is also the case with all other kinds of tools of communication, for instance the usage of false colour photographs in astronomy. Here, scientists have to learn that those colours can, for example, indicate different altitudes (see Figure 2.12) or different kinds of radiation (see Figure 2.2). Thus, de Regt has a point in highlighting the fact that scientists have to acquire certain skills and background knowledge to interpret such images correctly.

However, and contrary to de Regt, I think that, as image perception is just a special case of perception in general, it allows us to utilise the cognitive advantages provided by the evolutionary development of our visual apparatus. We are able to grasp non-conceptual content via images and we are particularly skilled in pattern detection. The example of the discovery of gravitational waves, discussed in the introduction to this book, is relevant at this point. Although the observer might not be familiar with the particular style of depiction of the diagram presented as evidence of this discovery (see Figure 1.2) and the theoretical assumptions supplying the background to this depiction, she might nonetheless be able to see the similarity between both curves. Thus, a kind of basic information seems to be transferable by visual means that does not presuppose prior education in interpretation.

This way of arguing, however, implies that people somehow deprived of the possibility of visually accessing the world, that is, in particular blind people, will not be able to acquire certain qualitative dimensions of non-conceptual information connected to the visual mode of accessing them. Information about colour and brightness might be paradigmatic examples here, whereas spatial information might also – at least partially – be accessed by tactile or aural means.

4.3.4 Interim results: scientific images as a source of knowledge and understanding

Whereas in the previous two sections our considerations have mainly concerned the possibility of transmitting and acquiring propositional knowledge via using visual representations in scientific discourse, this last section is meant to broaden the focus.

From an epistemological point of view, especially when recalling the prevailing sceptical attitude of traditional analytical philosophers towards this topic, that scientific images can indeed yield propositional knowledge under certain circumstances is a result of some interest. Nonetheless, such a conclusion still does not seem to be an entirely satisfactory answer to Perini's question of why scientists use these images in the presentations of their results. If transmitting propositional knowledge were the only undertaking, linguistic expressions could clearly also be employed. Why therefore be concerned with visual representations? This laid out the framework in this last section to further analyse the cognitive value of scientific images. The question of whether additional merit is inherent in the practice of utilising visual representations in communicative contexts that cannot be dealt with by other kinds of representation or not is investigated at this juncture.

The approach to this topic is based on the analysis of the *process of learning* as a paradigmatic cognitive process. A successful accomplishment of this cognitive undertaking yields two separate epistemic desiderata: knowledge and understanding. Both are not only relevant in educational contexts, but also of major importance in scientific epistemic practices in general. The questions asked are whether and how visual representations can contribute to these epistemic achievements. Table 4.1 summarises the main results of the above analysis on this topic.

The focus on the cognitive process of learning chosen for this analysis permits results obtained in empirical case studies in educational psychology and adjacent disciplines such as cognitive science and neuroscience to be taken into account. Amongst other things, it is made clear that certain constraints on the epistemic efficiency of images are a consequence of the recipients' cognitive set-up. That is, the characteristics of students (for example, background knowledge, preferred form of information presentation, etc.) are relevant considerations, as are the challenges posed by the interplay between different representational means deployed to transmit information – the problem of

Table 4.1 The cognitive value of visual representations in processes of learning

Cognitive achievements	*Potential cognitive achievements via visual representations*	*Capacities of visual representations enabling these achievements*
Knowledge	Propositional knowledge (knowing-that)	Perceptual mode of information access (presupposition: possession of relevant concepts)
	Practical knowledge (knowing-how)	Perceptual mode of information transmission allows communication of visual demonstrations
	Phenomenal knowledge / knowledge by acquaintance	Transmission of non-conceptual content supports mental images
Understanding	Grasping of connections between concepts and theories	Perceptual mode of information transmission can trigger retrieval of relevant background knowledge (dual coding theory)
		Perceptual mode of information transmission makes the display of relations and computational advantages possible (visual argument hypothesis)

integration (see e.g. Renkl and Scheiter 2015, online first). Thus, the results obtained in educational psychology made particularly plain that it is not exclusively due to the kind of representational means deployed in the context of learning, but to other contextual matters as well, that the latter can be effective in the way intended.

Moreover, the above discussion of two theoretical approaches, namely the dual coding theory and the visual argument hypothesis presented in detail by Vekiri (see Vekiri 2002), not only illustrates that visual representations can indeed have a positive impact on learning processes, but also reveals insights into how exactly they influence the recipients' cognitive apparatus to enable this positive outcome. The main aspects are summarised in Table 4.1.

At first sight, it might seem puzzling that the results obtained in educational psychology are only attributed to the facilitation of understanding, but that this first impression might somehow be misleading is due to the following reasons.

Firstly and admittedly, the capacity to offer information about individual elements and their relations, illustrated by proponents of the visual argument hypothesis, also affects the acquisition of knowledge, in particular knowing-that. In this sense, their results are also of relevance to this epistemic achievement of learning. As these kinds of contribution of visual representations to knowledge acquisition are, however, implied by the recipients' perceptual way of accessing the encoded information, they are not mentioned separately in the table. A similar point has to be made about the possibility of storing visual information in the human brain, a thesis entailed in the dual coding theory. This clearly belongs to the capacity of images to transmit non-conceptual content. This is why it is not listed as a separate point. Furthermore, the remaining aspects of the processing of visual information and its cognitive merits seem to belong rather to the facilitation of understanding than to the mere amassing of units of information.

Highlighting the fact that images often contribute to the achievement of scientific understanding does not imply a devaluation of the epistemic capacities of visual representations. This has been one of the main arguments presented above. On the contrary, the thesis was defended that this is one of the epistemic merits that make visual representations epistemically worthwhile when used in scientific discourse. Philosophers such as Elgin, Kvanvig and Kosso are right in pointing out that understanding bears an intrinsic epistemic value. Examples show convincingly that something important is lacking if knowledge is acquired without understanding. Thus, giving substance to the claim that visual representations can bring about this valuable epistemic desideratum, as the theses of educational psychologists based on and proven by empirical studies do, is of great importance to the project of correctly explaining the epistemic status of scientific images.

The second epistemic merit resulting from the above analysis is related to the epistemic desideratum of knowledge. In addition to the capacity to convey propositional knowledge under certain circumstances, visual representations can also transmit practical knowledge, i.e. a kind of knowledge usually regarded as not communicable and, therefore, as epistemologically inferior to propositional knowledge (see Grundmann 2008, 86). Moreover, showing that visual representations can be used to transmit this kind of knowledge suggests that some standard of correctness can be applied to it. In this sense, the second objection mentioned by Grundmann, namely that knowing-how is not related to truth in any epistemologically relevant sense, can be called into question. Our rejoinder to this objection has been to show, by again drawing on results from educational psychology, that there are patently at least some paradigmatic instances of a correct and successful application of practical knowledge that can be transmitted via visual representations. One purpose of empirical studies in educational psychology also consists in an approach to these optimal ways of visually presenting certain information. Images are constantly subjected to redesigning processes to improve them for educational purposes. Thus, the standards of correctness suggested for practical knowledge also bear on image design and its subsequent development in educational contexts.

Beyond that, it has been argued that using visual representations to transfer practical knowledge also considerably increases the number of recipients. Direct demonstrations of knowing-how usually only reach a small group of people. Making use of images, on the other hand, not only allows the transmission of knowing-how on a synchronic level to a broader audience, but also on a diachronic level, as they can e.g. be published in textbooks or distributed in electronic learning courses and employed in students' education for several years.

Finally, an additional epistemic merit that visual representations can occasion is to provide recipients with concrete mental images. These images can be mentally manipulated to search for solutions to problems, as proponents of the visual argument hypothesis claim. Closely related to this point is also the fact that mental images play a significant role in that they enable counterfactual reasoning in science. Weighing and deciding between alternatives presupposes a clear understanding of the facts at hand – and, as has been shown above, sometimes this understanding cannot be achieved properly without visual representations that might also provide the scientists with a clear visual conception, i.e. a mental image, of the entity in question. Last but not least, Jung makes us aware that these images can also be used as tools for mental training to improve the deployment of skills obtained later (see Jung 2012, 181).

All of these virtues are based on the fact that we make use of our visual perceptual apparatus to cognitively access information presented in scientific images. This way of deciphering the content allows us to draw on special skills related to vision, such as pattern detection, and we can gain access to non-conceptual content transmitted by visual means.

None of the three epistemic achievements discussed above, that is, the facilitation of scientific understanding, the transmission of knowing-how and the conveyance of mental images, can be properly attained if we make use of other representational means in scientific discourse. These are then the three merits that answer Perini's question about why it is that scientists use visual representations in the explanatory context of science.

4.4 Summary

In this chapter, the discussion has been on the question of the exact epistemic status of visual representations in the explanatory context of science. The investigation has focused on a comparative task: how the epistemic status of scientific images in comparison with other representational means – chiefly with linguistic expressions – is to be conceived.

The starting point of the analysis was a detailed discussion of Perini's theses on the topic. Her analytical approach to the subject matter at hand paved a way to revealing the diverse epistemic threads connected to the usage of visual representations in scientific discourse. One of the first aspects discussed in detail was the possible role of images in scientific arguments. Here, Perini insisted on their independent epistemic relevance. She made us aware of the fact that, although scientists treat visual representations as proper parts of scientific arguments, philosophers of science tend to neglect their epistemic value.

The next step was to get a better understanding of the nature of the philosophical problem lurking in the background and usually put forward as a rationale for this neglect in the philosophy of science. It became clear that at least two closely related aspects play a role in this. On the one hand, Steinbrenner points out that analytical philosophy is largely focused on language. On the other hand, this focus is still being passed on in the development of this philosophical school, in particular by maintaining Frege's theses on thoughts – later called 'propositions' – as the truth-bearing contents of sentences that can be transmitted and be subjected to logical operations such as negations. Having initially set too narrow a focus on language might have tempted some philosophers to regard propositions themselves as language-like entities. However, even if we are not trapped within this narrow-minded framework, Frege's argument that only propositions are proper candidates to bear truth values makes it rather difficult to maintain the claim that visual representations can make serious epistemic contributions in the context of scientific arguments.

Perini's solution to this problem is based on Goodman's theory of depiction. His account constitutes the framework that she employs to clarify whether images are indeed bearers of truth values and therefore permissible components of scientific arguments. Earlier in this book, however, Goodman's account has been rejected as a suitable approach to theorising about scientific images. Consequently, my solution diverges from the one suggested by Perini, although her analytical approach to the topic motivated my own reasoning.

In the following, we analysed (a) whether visual representations possess a cognitive content of some kind, i.e. a content that can be transmitted via images in communicative contexts, and (b) we investigated the precise nature of such a presumed content. Maynard's ideas on this topic were utilised as a guideline for this investigation. He emphasises that it is counterintuitive to point out, on the one hand, the intimate relation between the development of images and language in human prehistory and to argue, on the other, for an inferior status of images in comparison to language today. Maynard urges us to reconsider the question why it is that we willingly admit that linguistic expressions can transmit thoughts, but are reluctant to allow visual representations to fulfil the same epistemic task.

Taking his challenge seriously, the suggestion was made to pay closer attention to the fact that our predominant way of accessing visually presented information is via perception. The question of what kind of information we are able to process cognitively via perception then seems to be related naturally to queries about the kinds of cognitive content transferable via scientific images. With this respect, two findings from epistemology were highlighted. On the one hand, contemporary philosophers usually regard perception as an epistemic source, yielding propositional knowledge. On the other hand, that we are able to perceive entities for which we do not have concepts, particularly manifested by Hentschel's example of the first observations of the granulation of the solar surface, makes it plausible to claim that the content of perception can be non-conceptual in kind. Contrary to Grundmann, who took this to support the thesis that it is only non-conceptual – and, thus, non-propositional – content that can be transmitted via perception (see Grundmann 2008, 492f.), I argued for a more moderate claim, namely that the content of visual perception can be both propositional and non-propositional in kind. This seems to be possible because we acquire concepts by a mixture of testimony and perception. Initially we receive non-conceptual content via perception. This process is enriched in the course of our life by the concepts we acquire, which thus make the acquisition of propositional knowledge via perception possible, and constitutes a long-term development of our perceptual skills.

The analyses presented in sections one and two of this chapter made plain that scientific images can indeed yield propositional knowledge. Yet inquiring into the perceptual mode of accessing information transmitted by visual means also revealed further merits that can be brought about when using visual representations in scientific discourse. By taking into account that our perceptual apparatus has been shaped by evolutionary processes, it can be called our predominant way of cognitively accessing the world. Here, not only were our abilities of pattern detection and colour differentiation pointed out, but also that we can acquire non-conceptual content by perceiving the world.

The epistemic advantages of pattern detection for scientific purposes are immediately clear. Moreover, the human ability to grasp non-conceptual content via perception also suggests another way in which visual representations can contribute to scientific arguments. Non-conceptual content can be particularly relevant when images are regarded as evidence of observational results. Here, another epistemic merit of scientific images became salient: they can support the detection of anomalies to prevalent scientific hypotheses, because they can entail content that is not already conceptualised in the vocabulary of the theory at hand.

The epistemic merits employed by our perceptual apparatus to cognitively access visually presented information also laid out the framework for the last section of this chapter. Whereas the previous discussions suggested that some visual representations can indeed have parity with linguistic expressions when it comes to the transmission and acquisition of propositional knowledge, we finally inquired into the possibility that sometimes scientific images can exhibit epistemic merits that cannot be achieved by using other representational means. The discussion centred around the process of learning as a paradigmatic cognitive process, and that successfully accomplishing the process of learning yields both knowledge and understanding.

The contributions that visual representations can make to bring about these two epistemic desiderata were examined. On the one hand, because of the capacity to transmit non-conceptual content and the perceptual mode to access visually presented information, scientific images can supply recipients not only with propositional knowledge, but also with knowing-how and mental images. Thus, not only can some images transmit kinds of knowledge usually regarded as incommunicable (see Grundmann 2008, 86), but they also allow us to bring the information thus gained to a cognitive effectiveness relevant in scientific reasoning, such as the manipulation of mental images to work on solutions to problems. On the other hand, by taking into account empirical results from educational psychology and adjacent academic disciplines, it became comprehensible in what sense images can contribute to scientific understanding, defined as the grasping of connections between concepts and theories as propounded by Kosso and others (see Kosso 2007, 179). Moreover, by acknowledging that understanding is intrinsically epistemically worthwhile, another important epistemic merit of visual representations, namely to facilitate understanding by being integrated into scientific discourse, was thereby revealed.

To be concise, this analysis not only demonstrated how scientific images can contribute to scientific arguments and yield propositional knowledge, it also made clear in what sense at least some visual representations in certain contexts can facilitate epistemic achievements that are not attainable via other representational means. Of course, only a claim about possibilities shall be defended here. Visual representations and also other vehicles of communication are subjected to certain constraints when realising their epistemic effectiveness. As we learnt from educational psychology, learner characteristics play an important role in this respect, as does the design of visual representations. Not all ways of visually presenting information are likewise appropriate to any epistemic context. Admittedly, as visual representations have become a tool of expressing human thoughts – 'thoughts' here in a broad sense – they have also become subject to developmental processes of refinement and modification, as linguistic symbols have also. Visual skills have to be trained to decipher correctly the many different ways of visually presenting information.

Having pointed out that visual representations can indeed be epistemically effective, and acknowledging the fact that they play an increasing role in science and society, some new responsibilities for scientists that appear in this constellation will be discussed briefly in the next chapter.

Notes

1 Taking ethics of science into account, we should add that it is not only epistemic practices that are subjected to such evaluations and improvements, but also practices that give rise to moral questions.

2 It has to be added, however, that the considerations on justificatory reasons and practices, presented in the previous chapter, already exceeded a merely descriptive approach. We not only investigated how scientists *do* justify their epistemic practices, but also discussed the question of how they *should* justify their practices. Thus, the normative dimension was already inherent to our previous line of reasoning.

3 The model of information transmission used in the following discussion is based on related discussions in social epistemology, in particular in the debate about knowledge by testimony. For an introduction to the "transmission model of testimony" see Gelfert (2014, ch. 7).
4 This focus on knowing-that in epistemology, however, has not stayed uncontested. Eva-Maria Jung, for example, tries to make a case for including also "practical forms of knowledge", as she calls it, referring thereby to knowing-how (see Jung 2012, ch. 1.5).
5 This argument is presented in a similar fashion by Maynard (2009, sect. 2).
6 Relevant discussions of the topic are especially connected to attempts at establishing a picture language, as mentioned in section 2.2 of this book.
7 This is a translation of his paper *Der Gedanke. Eine logische Untersuchung* published in German in 1918/1919 (see Frege 1993, 30ff.).
8 It has to be added that not all philosophers of science would agree that *truth* is the (ultimate) goal of science. Usually it is scientific realists who defend a claim along these lines, although most of them admit that other epistemic desiderata and also practical concerns might play a role. Thus, Ilkka Niiniluoto points out that there is no reason to assume that the cognitive aim of science has to be "one-dimensional", that is, exclusively directed towards truth (see Niiniluoto 2015, ch. 2.4). Moreover, scientific anti-realists such as Bas C. van Fraassen explicitly deny that truth is the goal of science. Van Fraassen claims that scientists' sole aim in their epistemic endeavours is "empirical adequacy" (see van Fraassen 1980, 12).
9 He adds however that the captions of pictures can indeed be true or false, and discusses some interesting examples in this respect (see Gombrich 2004, 59ff.).
10 Contrary to my suggestion, Richter accepts Goodman's theory as the guiding model to make sense of the concept of scientific visualisations and tries to modify Perini's work within this framework (see Richter 2014, ch. 4.2.2ff.). Having made my reasons sufficiently clear why I think that Goodman's theory of depiction is not a suitable means to make use of in this context, Richter's approach will be put aside without further discussion.
11 In logics, *arguments* are usually considered to be purely linguistic in kind (see Salmon 1983).
12 Meanwhile there is an extensive branch of studies flourishing on what might be called 'diagrammatic reasoning', some of them with an even more wide-ranging interest in diagrams and their role in epistemic reasoning than merely considering those mentioned above (see e.g. Giardino and Greenberg 2015; Shin, Lemon and Mumma 2014; Shin 2015; Stenning 2002; Tversky 2011 and references therein). Moreover, there are investigations into the possibilities of establishing completely visual logics (see e.g. Bagusche 2012).
13 A fascinating example is Oliver Byrne's book dedicated to the attempt to offer complete visual demonstrations and proofs of Euclid's theorems – also meant as an attempt to introduce this complex material without using linguistic expression, and therefore supposed to be more easily comprehensible than a linguistic tractate on the topic might be (see Byrne 2013). Again, a lively debate also started about the relevance of visualisations in mathematics (see e.g. Brown 1996; Mancosu, Jørgensen and Pedersen 2005; Sazdanovic forthcoming and references therein).
14 Richter mentions this as option (iii) of how images can play a role in scientific argumentation (see Richter 2014, 159).
15 IUPAC is an abbreviation of 'International Union of Pure and Applied Chemistry'.

16 Unfortunately, Scholz does not explain why he makes a distinction between contexts of usage and cultural contexts. It might be objected that cultural contexts are simply descriptions of contexts of usage. Ethnologists might offer explanations as to why we make use of certain images, and these explanations could then be called 'cultural contexts'.

17 Some of the ideas that are presented in this section are also discussed in Mößner (2013b).

18 Ana Laura Nettel and Georges Roque call this clear-cut distinction between persuasion and argumentation, between *pathos* and *logos*, into question. In particular, they doubt that the role of visual representations can exclusively be characterised as a kind of visual rhetoric. Contrary to this, they point out that although visualisations are often regarded as emotionally influencing, these representations can nevertheless play an argumentative part (see Nettel and Roque 2012, 67).

19 This is also the way Vögtli and Ernst term the epistemic role of visual representations in argumentative contexts, in particular the role of visualisations produced by scientific instruments (see Vögtli and Ernst 2007, 36).

20 A similar debate takes place in the philosophy of film (see Wartenberg 2011b, 12f.). Can what has been visually presented in a film be translated or paraphrased? One might argue that, as films are audiovisual media, the verbal argument can simply be peeled out of the mix. Yet this is not what the philosophy of film is about. Wartenberg makes this clear when stating that "[t]he crux of the debate is whether films within the standard genres of filmmaking – from fiction films to documentaries and even avant-garde films – can actually do more than raise a philosophical question or record a philosophical argument, whether some films should really be counted as doing philosophy on their own" (Wartenberg 2011a, 551). Proponents of film philosophy try to show that some films are capable of philosophising by filmic means only. That is, films are said to make significant contributions to philosophical debates. These contributions are transmitted in the audiovisual style of the medium itself and cannot be translated into other representational means. Stephen Mulhall, for example, defends this ambitious thesis (see Mulhall 2008).

21 An overview is offered by McGrath (2014).

22 Laurence BonJour (2013) offers an overview on different epistemological approaches to this topic in BonJour.

23 For more information about the space mission see www.nasa.gov/mission_pages/newhorizons/main/index.html, accessed May 24, 2016.

24 The topic of understanding as an epistemic desideratum in science will be dealt with in more detail in section 4.3.3 of this book.

25 Abstract paintings, for example, do not belong to this set of visual representations in Sober's sense. Neither does he extend his theory to maps, diagrams, or graphs that mix different representational modes. Blair's account is thus much broader in scope.

26 This point is also highlighted by Dieter Mersch who argues that, although images can show entities (for example, people and their actions), they cannot show a negative state of affairs (see Heßler and Mersch 2009, 19ff.).

27 At least not without the aid of further symbolic auxiliary means, such as crossing out the content of a particular image to express that what it shows is not the case.

28 A discussion of recent approaches to this topic is provided by Gendler and Hawthorne (2009); Nanay (2014) and Schantz (2009).

29 Scholz (2004) offers an insightful discussion of the common metaphor of *epistemic sources*.

30 Philosophical sceptics have to be mentioned as an exception here, as some of them do not regard perception as a reliable source of information about the external world. However, scepticism seems to be a philosophical problem in its own right that needs not be restricted to particular epistemic sources, it being about the *possibility of knowledge* in general. More information about how scepticism is related to perception is offered by Grundmann (2008, ch. 7.1).

31 Eric Margolis and Stephen Laurence (2014) discuss different approaches to the concept of concepts.

32 Further reasons are discussed by José Bermúdez and Arnon Cahen (2015, sect. 4.1).

33 It has to be added that Peacocke does not speak about 'representation' in this context, as he takes this to involve figurative meaning. That is, the image of an aurochs in the Altamira cave can also be meant to represent success in hunting, not a particular animal. Such instances of a more wide-ranging meaning attribution via representation, Peacocke explicitly wants to exclude from his theory of depiction (see Peacocke 1987, 383). Thus, when speaking about 'representational qualities' in the following discussion of his ideas, I will use the concept in accordance with those constraints that result from his theoretical approach.

34 Admittedly, this visual experience has to be repeated several times to learn the relevant characteristics.

35 Artists, particularly fresco painters, are confronted with the problem of how to trick the human eye in a way that their paintings, situated on ceilings etc. and therefore often regarded from unfavourable angles, acquire their appropriate proportions nonetheless. Here it is the reverse, that is, spatial properties of the frescoes are willingly distorted so that their shapes appear without distortion in the recipient's perceptual experience of them. Another example of tricking the eye in the domain of art is *anamorphoses*.

36 With regard to this difficulty see in particular his explanations in Fleck (1986d).

37 The topic of anomalies in observations is most famously discussed by Kuhn, who suggests that anomalies constitute bones of contention that will finally necessitate a shift in the prevalent paradigm (see Kuhn 1996, ch. 6).

38 I have discussed this in more detail with regard to the training of journalists and their abilities to check their sources of information for accuracy.

39 The following website offers access to more than 40 projects of this kind, see www.zooniverse.org, accessed January 11, 2016.

40 What decisions have to be made by the user in her classificatory task is visualised in the decision tree produced by Coleman Krawczyk (University of Portsmouth), see https://data.galaxyzoo.org/gz_trees/gz_trees.html, accessed January 12, 2016.

41 Marcel Boumans (2016) also discusses the relevance of human vision or, as he puts it, of the eye as "a reliable tool for judgment" in science.

42 As an interesting spin-off, it can be added that this interrelationship between the indicative colouring of potential prey and the predators' ability to perceive those colours triggered another evolutionary process which somehow aims at undermining the initial effect. Harmless potential prey have developed visual

characteristics of dangerous or poisonous species to lead their predators astray. Hoverflies, for example, look like wasps.

43 Schawelka also discusses these phenomena, subsumed under the label of 'reflectance'. He thereby refers to the ability of objects to reflect, absorb or transmit photons. Which of these abilities are realised depends on two aspects, namely (1) the structure or texture of the respective object and (2) the energy of the respective photon, i.e. the wavelength of the light (see Schawelka 2007, 45).

44 Of course, it is not only in regard to colour perception that scientists have tried to overcome the limitations of the human eye, as the astrophysicist Thorsten Ratzka, for example, has pointed out in his retrospective description of human observations of celestial objects (see Ratzka 2012).

45 His main examples are drawings, but he also applies his analytical results to other kinds of images, in particular to photographs and diagrams.

46 An overview of different accounts in the context of argumentation theory is presented by Jens E. Kjeldsen (2015, ch. 2).

47 Downes mentions this line of reasoning in his epistemological analysis of scientific images and attributes it to Pierre Duhem by stating that it was "[…] Pierre Duhem's position that it was only human weakness that resulted in visual aids being required in the service of science" (Downes 2012, 117). Obviously, Downes hereby refers to Duhem's theses on the two kinds of the human mind which the latter presents when discussing the relevance of models in science (see Duhem 1998, ch. 4). From his point of view, it is due to a missing capacity of reasoning in abstract terms that some people need models or visual means of another kind to imagine the relevant relations in order to understand physical laws and theories correctly.

48 I thank Johann Marek for helpful discussions of this topic.

49 Some of the ideas presented in the following section have been published in Mößner (2015).

50 Of course, there may also be practical elements involved, for instance the practising of certain skills to acquire the relevant expertise for deploying them later on.

51 A multiplicity of ways to process and encode visual information mentally is also suggested by some of the case studies presented by the neuropsychologist Oliver Sacks. In *"The Mind's Eye"* (Sacks 2010, 202ff.), for example, he discusses the medical histories of different people who went blind in the course of their lives. Interestingly, some of them kept their ability to construct mental images, that is to visualise objects, in their minds, whereas others totally lost this ability. These latter patients were nevertheless able to learn empirical facts about their environments with the aid of their other senses. These medical case studies speak in favour of the thesis that there are at least two different cognitive subsystems for processing and encoding information, which can also be used separately if one of the systems is damaged or takes on new tasks from other parts of the brain.

52 The advantage of visual representations to trigger visual imagings that can be further manipulated is also discussed by Max J. Kobert who offers some helpful examples (see Kobert 2010).

53 Of course, there are innumerable design guides offering advice in this respect. In our previous discussion we have already learnt, for instance, about Frankel and DePace's suggestions (2012).

54 Michael P. Verdi and Raymond W. Kulhavy, for instance, mention *gender* as a relevant factor to consider when theorising about the educational efficiency of maps

(see Verdi and Kulhavy 2002, 33f.). Schnotz points out that the recipient's *age* can play a role (see Schnotz 2002, 113).

55 Regarding map comprehension, see e.g. Verdi and Kulhavy (2002, 33).

56 Hausken's and Roskies's analyses of fMR images in medical practices show nicely what happens in interpretive processes if people (experts or laypeople) wrongly assume that they are familiar with the results of new imaging technologies (see Hausken 2015; 2017; Roskies 2007; 2008).

57 Actually, he mentions three reasons. The possibility of cognitively processing knowledge can be regarded as a reason on its own.

58 Jung discusses a variety of these strategies in detail (see Jung 2012, ch. 1.4.3.1 and 1.4.3.2).

59 Personal conversation with Max Hoffmann.

60 There are different variants of this disease. Some can be so severe that the patient even loses her ability to understand linguistic expressions.

61 A critical discussion of Jackson's arguments, objections and rejoinders is offered by Martine Nida-Rümelin (2015).

62 Again it has to be added that, in particular, the student's background knowledge plays a major role with this respect. It might fill the gaps left open by the description at hand so that a proper mental image can nonetheless be construed by the learner. A similar case can be made for images. The information transmitted by them might be as incomplete as the information transmitted by a linguistic description. Consequently, images serving educational purposes have to be carefully chosen.

63 The most famous ones are discussed by Michael Huemer (2011, sect. 3).

64 For a critical discussion of such approaches see e.g. Koppelberg (1993).

65 A compilation of important works on the topic of metaphors is presented in Ortony (1998).

66 I discussed this point in more detail in Mößner (2013a).

67 In this sense, images might be regarded as a kind of extended memory system, so to speak, though I do not want to relate this to the debate about the extended mind here. An introduction to this debate is offered by Holger Lyre (2010).

68 Further examples of visual thinking in scientific and technological practices are discussed by Hentschel (2014, ch. 10).