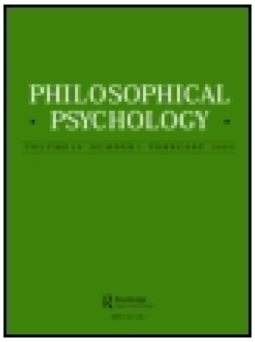

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A cognitive perspective on scientific realism

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ABSTRACT
The debate about scientific realism is concerned with the relation between our scientific theories and the world. Scientific realists argue that our best theories or components of those theories correspond to the world. Anti-realists deny such a correspondence. Traditionally, this central issue in the philosophy of science has been approached by focusing on the theories themselves (e.g., by looking at theory change or the underlying experimental context). I propose a relatively unexplored way to approach this old debate. In addition to focusing on the theory, we should focus on the theorizer. More precisely, in order to determine on which component of a theory we should hinge a realist commitment, we should analyze the cognitive processes underlying scientific theorizing. In this paper I do just that. Drawing from recent developments in the cognitive sciences and evolutionary epistemology, I formulate some tentative conclusions. The aim of this paper is not so much to defend a particular position in the debate on scientific realism but to showcase the value of taking a cognitive perspective in the debate.

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1. Introduction

The debate about scientific realism is concerned with the relation between our scientific theories and the world. Full-blown scientific realism argues that our theories correspond to the world. Anti-realists reject or problematize this claim in various ways. In contemporary philosophy of science, the great majority adopts a position somewhere in between these two extremes. While these authors often refer to their position as a realist position (why say the glass is half empty if you can say it is half full?), they strongly attenuate their claims of realism to make their position more plausible. They do so by introducing a series of qualifiers – only committing to our best scientific theories or "mature" sciences and arguing that they are "approximately" true instead of simply true – and often restrict their claims to particular aspects of a theory (e.g., entity

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realists restrict their claim of realism to the postulated entities of a theory, whereas structural realists restrict theirs to the structural part of a theory).

I do believe – with the majority of contemporary authors – that realism is not an all-or-nothing affair. The central question facing the philosopher of science therefore becomes the following: On what part(s) of a scientific theory can we hinge which kind of realist commitment?[1] Entity realists hinge claims of realism on postulated unobservable entities (such as electrons) because these entities are purportedly manipulated in experimental settings (e.g., Hacking, 1983). Structural realists hinge claims of realism on the structure of a theory rather than on the entities it postulates because this part of the theory has been preserved across theory change and accounts for its epistemic success (e.g., predictive success) (Worrall, 1989) or because doing so fits better with contemporary theories such as quantum physics (Ladyman & Ross, 2007). Finally, explanationists such as Kitcher (1993) hinge claims of realism on those aspects of a theory that account for its success, distinguishing "working posits" from "idle parts." On the other hand, Laudan (1981) refuses to hinge claims of realism on the central terms of successful theories, given that successful theories of the past often contain terms which we now believe do not refer.

In all of the accounts above, the focus is on theory and experiment. While this approach centered on theory and scientific activity has undoubtedly proven its worth, there is a different angle from which to approach the issue. In addition to looking at the products and activities of scientific inquiry, the philosopher of science should also look at the producer (i.e., the theorizer).[2] More precisely, she should look at the cognitive processes underlying human scientific inquiry. This relatively unexplored way of approaching the important issue of scientific realism could, I believe, prove very useful and cast new light on the matter.[3] The question at the heart of this new approach reads as follows: what cognitive process(es) underlie scientific theorizing and what does this tell us about the relation between the components of a theory and the world? Simply put, I want to show the relevance of a cognitive approach in helping us to decide on which part of a theory we can or cannot hinge which kind of realist commitment.

The primary aim of this paper is to show the relevance of a cognitive approach for the debate about scientific realism. In order to do so, I will show how such an approach could work, drawing some tentative conclusions from cognitive and evolutionary considerations. In Section 2, I set out the conceptual foundation for the rest of the paper. I introduce the two major components of scientific theories as well as what it means, for the purposes of this paper, to take a realist stance regarding these components. In Section 3, I look at the various cognitive processes and their (evolutionary) origin which underlies our theorizing. In Section 4, I pull the two threads together, formulating some tentative answers to the central question of this debate: About which component of a theory can we take a realist stance? In Section 5, I conclude.

2. Conceptual elucidation

As pointed out in the introduction, the three main kinds of selective realism are explanationism, entity realism, and structural realism. They each hinge claims of realism on certain components of a theory and not on other components. Explanationists are realists with regard to those components of theories that underlie their predictive success (e.g., Kitcher's (1993) "working posits") and not with regard to so-called "idle parts." Entity realists hinge claims of realism on the (unobservable) entities postulated by a theory, and structural realists hinge them on the structural, relational, or mathematical components of a theory. Postulated unobservable entities model "the furniture of the world" (e.g., genes, atoms, electrons, and quarks), and the structural part maps the relations among the phenomena described in the theory.

In this paper, I will focus on the debate between entity and structural realists. They each hinge claims of realism on one of the two major components of a theory. While dividing scientific theories into a "structural" and a "postulated entity" component is obviously a very rough division (more fine-grained distinctions are possible), it provides us with a workable framework which suffices for the purposes of this paper. I am also aware that it is not always clear what "structure" stands for or whether it can or should be equated with mathematical equations. In this paper, I take the two to be identical although some scientific theories may not have mathematical equations but do exhibit relational aspects, which complicates the matter. Nevertheless, despite these problems, I believe that this classification provides us with a good first approximation of the different parts of scientific theories in general and of physical theories in particular.

In addition to the different components of a theory on which we can hinge claims of realism, we can distinguish between different dimensions of realism. Chakravartty (2007) identifies three dimensions of realism: an ontological or metaphysical dimension, an epistemological dimension, and a semantic dimension. Ontologically, a realist is committed to the external, mind-independent existence of the world described in scientific theories. Semantically, a realist is committed to the claim that a scientific theory is to be construed literally. Epistemologically, a realist is committed to the claim that a theory or a component of a theory constitutes knowledge of the external world.

In this paper, I will focus on the epistemological dimension. Ontological or metaphysical anti-realism has fallen in desuetude since its heyday in the 18th century with Berkeley's idealism. Nowadays, most philosophers of science – even self-professed anti-realists such as van Fraassen (1980) – do not question the existence of a mind-independent external world. Regarding the semantic dimension, I will assume that taking an epistemological realist stance with regard to certain components of a theory means that we also take a semantically realist stance with regard to those components. This is not necessarily so. Idealists, for instance, do not think that scientific claims can be construed literally (since such claims are not believed to be about an external world), but they could concede that these scientific claims constitute knowledge of a mind-dependent world (Chakravartty, 2007, p. 10). Nevertheless, most authors who commit to epistemological realism also commit to semantic realism.

The central question addressed in this paper therefore becomes the following: What component of scientific theories constitutes knowledge about the external world? In order to illustrate the relevance of a cognitive approach, I will show how considering the cognitive processes involved in the theorizing of a "postulated entity component" and a "structural component" can help us to address this question. More specifically, my aim is to show how an analysis of the origin of these processes can help us to determine on which component of a theory we can hinge an epistemologically realist commitment.

3. Cognitive processes

3.1 The structural logico-mathematical component

Logic and mathematics are cognitive artifacts designed to support and enhance reasoning. Humankind developed these skills over time, and each of us has to learn these skills (with some effort, I might add). Cognitive artifacts range from tying a knot in one's handkerchief to help one remember something, writing to assist one's memory and reasoning processes, and the most powerful quantum computer helping one to compute huge amounts of data. The function of such artifacts is to assist and enhance human thinking, either by off-loading tasks to the environment (e.g., the knotted handkerchief takes over the task of reminding one of something, much as Hansel and Gretel's breadcrumbs take over the task of remembering the way back home) or by boosting one's ability to compute or represent information, functioning as a cognitive lever. Logic and mathematics belong to this second category.

Although numerical reasoning is grounded in innate cognitive abilities that we share with other animal species, proper arithmetic in particular and mathematics in general take us far beyond innate capabilities. Whereas some nonhuman animals and young children can enumerate numerical values up to three or four precisely and compute the outcome of simple addition and subtraction on these small sets (Wynn, 1992, 1995; De Cruz, 2008, p. 477), representing larger numerical values precisely requires external cognitive support. First of all, in order to represent large numbers precisely (i.e., numbers over 4), we need number words. Without this external scaffold, we'd be limited to representing only small numbers (i.e., up to 4) precisely (Pica, Lemer, Izard, & Dehaene, 2004). Secondly, to have semantic access to these large numerals and perform arithmetic operations on them, we need to represent them spatially along a number line (Dehaene, 2003).

Such spatial metaphors, it turns out, are fundamental when it comes to scaffolding mathematics beyond their humble origin. In their book *Where Mathematics Comes From*, cognitive scientists Lakoff and Nuñez (2000) argue that mathematics has been developed through all kinds of spatial metaphorical constructs. We conceptualize mathematical sets, for instance, by using the spatial metaphor of a container, and we represent geometric figures by conceptualizing them as objects in space. But it doesn't stop there. Supported by such metaphors we reasoned our way to zero, infinity, fractions, and all sorts of complex mathematical operations that make up our mathematical arsenal today. The result is an incredibly rich toolbox for representing and computing quantitative data in the world. It is a toolbox which, once in place, radically scaffolds our cognitive abilities.

As Lakoff and Nuñez (2000, p. 50) point out, what makes mathematics special is, on the one hand, its precision and consistency and on the other hand, its applicability to a wide variety of subject-domains. It provides us with an unyielding, stable conceptual framework (the same principles apply over time and across domains) that processes input in a great variety of ways. This makes it exceptionally generative. The upshot of this is twofold. On the one hand, given its consistency, mathematics enables us to overcome cognitive biases in particular domains. Logic too provides us with a consistent, stable framework and helps us overcome cognitive biases (more on this below). On the other hand, given its fecundity, mathematics radically extends our representational and explanatory reach beyond our innate, species-specific representations of the world.

A good example of how mathematics enables us to overcome cognitive biases is in the domain of probability, a domain in which our intuitive reasoning is notoriously biased and unreliable. Kahneman and Tversky (1972), Tversky and Kahneman (1982); see also Kahneman (2011) showed that our intuitive reasoning about probabilities systematically leads us astray. We estimate probabilities by using heuristics such as the availability heuristic – deriving how probable the occurrence of an event is from how easily it can be recalled or imagined – and fall prey to common pitfalls such as the base-rate fallacy. A normative, mathematical (Bayesian) framework guards us against such biased reasoning. It provides us with a sturdy and objective framework to compute probability, bypassing our intuitive estimations and correcting them when necessary. Logic, as pointed out, provides us with another safeguard against intuitive reasoning errors. As Tversky and Kahneman (1983) have shown with their famous "Linda problem,"[4] following intuition, we are vulnerable to falling prey to logical fallacies such as the conjunction fallacy. Applying logic to the problem, however, sets our reasoning straight. Once again, a formal and stable framework enables us to bypass our intuitive inferences, correcting us where necessary.

More than just straightening human reasoning, mathematics has led us to a radically transformed understanding of the world. It is very much at the core of modern scientific theories which have revolutionized our view of the world. In the prescientific era, our worldview was largely determined by our intuition. This intuition, according to cognitive developmental research (e.g., Spelke, 1991; Baillargeon, 1991 on innate physical intuitions in infants) and comparative anthropological research (e.g., Atran, 1998 on cross-cultural similarities in carving up the natural world), is to an important extent an innate evolutionary heritage. We are genetically predisposed to interpret our physical environment (i.e., the realm of inanimate objects), natural environment (i.e., the realm of organisms), and social environment in a particular way (Vlerick, 2012, 2017). The evolutionary story behind these species-specific and innate perspectives, of course, is that they provided our ancestors with useful frameworks to deal with important aspects of their environment regarding survival and reproduction. Boyer (2000) refers to the intuitive principles guiding our reasoning in these particular domains as an "evolved metaphysics." He calls these innate knowledge systems "intuitive ontologies."

As can be expected, these intuitive ontologies are both contingent – being the result of one particular evolutionary path – and faulty. Tellingly, our intuitive physics holds that an object's natural state is at rest and that movement only occurs when a force acts upon it. Newton of course rejected this core intuition about the physical world, showing that an object continues indefinitely on its trajectory, only coming to a stop when a force acts upon it (that force being friction and gravity, on our planet). While our intuitive notions work perfectly well for dealing with medium-sized dry goods in a friction-ridden environment where gravity rules supreme, they do not correspond in any way to the fundamental laws of physics.

In order to move away from our innate, erroneous, and tenacious intuitions, we need the cognitive resources to interpret the empirical data in a different way. That is where mathematics comes in. Given its generative power, it enables us to represent and compute quantifiable information in myriad ways yielding representations, explanations, and predictions of phenomena that would otherwise be far beyond our cognitive reach. By unleashing mathematical analysis on information we gather from the world, we are therefore not only able to represent it in a more consistent and unbiased way, but also in a much more fine-grained way. The crude representational framework of our intuitive physics is no match for the mind-bogglingly complex theories of contemporary physics.

Without mathematics, it is safe to assume, there would not have been a Newtonian revolution, let alone an Einsteinian one. With our intuitions firmly in the driver's seat, we would quite plausibly be stuck in a geocentric, pre-scientific worldview. How indeed were we to reject our genetically anchored default mode of representing the world without rigorous measurements and mathematical computations revealing that the world is not always as it appears?

Therefore, more than just enhancing our reasoning, formal systems of representation such as logic and mathematics provide us with a cognitive scaffold to transcend what von Uexküll (1909) has called our "Umwelt" – the particular realm of awareness in which every species is encapsulated, as the outcome of its perceptual and innate conceptual categories. It takes us from a species-specific view of our environment with no particular ontological authority (given that it evolved to produce survival- and reproduction-enhancing behavior in a particular species confined to a particular environment) to a radically broadened and objective or, at least, less species-dependent representation of the world (i.e., a representation which is not crafted to fit our particular evolutionary needs).

3.2 The postulated unobservable entity component

Postulated unobservable entities are in a very real sense conceptualized as miniature objects. Electrons are little particles swerving around nuclei; nuclei are agglomerations of smaller particles (protons and neutrons) which, again, are composed of even smaller particles (quarks). In textbooks, these postulated entities – ranging from molecules to quarks – are typically depicted as spheres. The microscopic realm, it seems, is modeled according to our perception of the macroscopic realm.

According to Krellenstein (1995, p. 242), perception-based concept formation is at the basis of concepts providing causal explanations of physical entities and properties. McGinn (1989, p. 358) refers to this as the "principle of homogeneity." The theoretical models we use to describe the world are shaped by an analogical extension of what we observe. In this regard, we arrive at the concept of a molecule which is based on our perceptual representations of macroscopic objects extended to smaller-scale objects of the same kind.

Cognitive developmental research shows that the notion of "objecthood" is genetically wired and present at birth. Kellman and Spelke (1983) tested three-month old infants on their physical intuitions and discovered that infants carve the world up into objects and expect them to obey a number of laws. We do not come into this world in a "blooming and buzzing confusion" – as William James (1890) conjectured – but impose a ready-made conceptual and perceptual framework on our environment. These core intuitions, which infants could not have gathered from conventional learning processes, still underlie the way we approach our physical environment on an intuitive level as adults. They constitute an evolved species-specific framework to deal with the physical world.

This framework is a product of the environmental conditions to which our perceptual and conceptual apparatuses are attuned. Were we organisms the size of bacteria, our environment would be radically different, and viewing the world as an empty space containing objects would probably not serve us very well. Perceiving and imagining objects is therefore very much a contingent product of the brain and senses which evolution endowed us with.

Moreover, the perceptual basis of modeled entities is the product of our sensory apparatus – more precisely, our visual apparatus. The fact that mental imagery is connected with our sense of vision is – next to being supported by our everyday observation (mental imagery has a distinct visual quality to it) – confirmed by extensive empirical evidence. First of all, engaging in mental imagery activates many of the same neural correlates as visual perception (Kosslyn, 1980). Moreover, when people hold a mental image in their mind, their eyes make the same kind of rapid, unconscious flicks – called saccades – that they would if they were actually observing something (Brandt & Stark, 1997; Laeng, Bloem, D'Ascenzo, & Tommasi, 2014). Furthermore, when people consciously move their eyes, thereby distorting these saccadic eye movements, their mental image is disrupted (Laeng et al., 2014). All of this strongly suggests that mental imagination is intimately connected to vision.

In this regard, the particular sense of vision we have evolved provides the substrate for the perception-based models we produce through imagination when theorizing about the world. That is not coincidental. As primates, we rely primarily on our sense of vision. Our representation of the world is mainly a visual one, as opposed to that of many other animal species who rely more on their olfactory sense, their auditory sense, or both. This dominant sense, rather than just providing us with the set of data upon which we rely the most in our interaction with the environment, also underlies the way in which we as cognitively highly developed primates come to conceptualize the physical world. This entails that different senses – or even just a different dominant sense – would have provided us with a different substrate to model the world.

Modeling the microscopic world in visualizable entities is nevertheless an integral and important part of scientific research and discovery. Interesting in this regard are the different kinds of models used in science. Barbour (1974, pp. 29–30) distinguishes between four kinds of models. The first kind are experimental models, designed to solve practical problems such as, for instance, wind-tunnels that are used to gauge the lifting force of a particular wing structure of an airplane. The second, at the opposite extreme, are logical models – formal deductive systems based on axioms and theorems. These models deal exclusively with ideas. The third kind are what Barbour calls mathematical models. They are symbolic representations of quantitative variables in physical and social systems, such as, for instance, equations expressing the relation between supply and demand in economics. These models mirror their object in formal structure. They are, in reference to the different components of a theory outlined above (see Section 2), the structural component of a theory. Finally, the fourth kind are theoretical models. These modules are aimed at representing the underlying structure of the world. In order to do so, they postulate imaginative mental constructs accounting for the observed phenomena. They make out the so-called "postulated entity component" of a theory.[5]

According to Barbour (1974), these postulated imaginative mental constructs are shaped by analogy with familiar mechanisms and processes. Theoretical models, such as, for instance, the billiard-ball model of gas which postulates that gas is composed of tiny spheres bouncing around and colliding like billiard-balls, enable the development of theories involving equations that, in this example, interrelate the mass, velocity, energy, and momentum of these hypothetical spheres (pp. 30–31). These models, Barbour argues, need not be picturable as such. We can selectively suppress visual features, such as when imagining colorless elastic spheres, but nevertheless, they must be conceivable. They must, according to Barbour, be intelligible as units, providing us with "a mental picture whose unity can be more readily understood than that of a set of abstract equations." They do, therefore, make use of visual imagery (Barbour, 1974, p. 33).

However, theoretical models have more than a textbook function. As Barbour (1974) points out, scientists report that visual imagery often predominates over verbal and mathematical thinking in scientific discovery (pp. 33–34). In other words, visual models drive the development of new insights and theories. Notably, Einstein wrote to Hadamard the following:

> The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be 'voluntarily' reproduced and combined … This combinatory play seems to be the essential feature in productive thought before there is any connection with logical construction in words or other kinds of signs which can be communicated to others. (quoted in Tucket, 1988, p. 78)

In support of this anecdotal evidence, a number of cognitive scientists and philosophers have pointed out the crucial role of visual imagery in cognition. Some influential scholars, such as Barsalou (1999) and Prinz (2002), even consider it to be the foundation of all human cognition. They defend a so-called "perceptual theory of knowledge," in which they argue – much like the British empiricists, for that matter – that our fundamental concepts and ideas are ultimately grounded in perception and mainly in visual perception. According to Barsalou (1999), the fully functional conceptual toolbox we possess, including the abstract concepts we entertain, is ultimately derived from perception. First, we extract schematic representations – for example, 'green' – from perceptual experiences. Then, we store and organize these perceptual symbols. Finally, we freely manipulate and recombine these symbols, working our way up to a full-fledged conceptual system. Gauker (2011) doesn't go as far. He rejects the idea that abstract concepts or ideas are grounded in or can emerge from perception in general and visual imagery in particular. Nevertheless, he concedes that visual imagery plays a vital role in human cognition. It precedes language and forms the basis of what he considers to be an instrumentally powerful, imagistic kind of thought.

4. Pulling the threads together: Some tentative conclusions

Given the cognitive processes underlying our scientific theorizing, we can draw some tentative conclusions with regard to the question about the component of a theory on which we can hinge a realist commitment. In Section 2, I distinguished between two major components of scientific theories: the structural and the postulated entity component; and I focused on the epistemological dimension of realism.

4.1. Structural component

4.1.1. The case for realism

The building blocks of the structural component of a scientific theory are mathematical and logical reasoning. One strategy to gauge whether or not a realist attitude toward the structural component is warranted would be to look at this component's performance. Worrall (1989), in this regard, points out that as theories change, the structural part (as opposed to the postulated entity part) of previously successful but ultimately rejected theories often emerges unscathed, or, at least, the equations of the old theory are kept as limiting cases of the equations of the new one. This, he argues, warrants a realist attitude toward the structural component. Moreover, as Worrall (1989) points out in that same paper, the predictive and explanatory success of scientific theories is ascribable to its structure. For instance, what enables us to make accurate predictions are the mathematical equations of theories. Doing so, he adopts the "no miracle argument" (which is widely considered to be the most important argument for scientific realism) with regard to the structural part of successful theories. It would be a miracle (i.e., an extremely improbable coincidence), the argument goes, if the equations of a theory did not represent actual structures of the world, given their "unreasonable" success in predicting future states of the world.

In a similar vein, Wigner (1960) has famously pointed out "the unreasonable effectiveness of mathematics in natural science." Mathematical representations have had enormous predictive and explanatory success in the natural sciences, and mathematical concepts can often be applied in different contexts than the one in which they were originally developed. The view that mathematics is an uncannily effective tool for interpreting the structure of the physical world and enabling predictions about it is as old as modern science itself. The great Galileo (1623), one of the founding fathers of modern science, surmised that the book of nature is written in the language of mathematics.

The cognitive approach that I propose supports the conclusion of these important arguments that are in favor of a realism regarding the structural part of a theory, but it supports them from a different perspective. Logic and mathematics, I have pointed out, are cognitive levers. They provide us with a more objective and complex understanding of the world and take us far from what Boyer (2000) calls our "intuitive ontologies." Since these ontologies have been shaped by natural selection to solve a number of recurring problems related to survival and reproduction in the particular ecological niche occupied by our ancestors, we may raise the skeptical worry that they are ill-suited to represent the world in an objective way. From an evolutionary perspective, our innate intuitive thinking emerges as a useful but ultimately contingent framework with no particular authority when it comes to representing the fundamental features of the world. There is no reason indeed to assume that our *umwelt* provides a more objective perspective on the world than, for instance, that of an octopus or a migrating bird.

This, however, does not mean that evolution by natural selection is not a truth-tracking process. In fact, in previous work, I have argued that it is (Boudry & Vlerick, 2014). The truths that our intuitions have been selected to track are confined to a narrow, ecologically relevant context, not the general, fundamental context science is concerned with (see also Vlerick & Broadbent, 2015; Vlerick, 2014; Vlerick, 2017; Vlerick & Boudry, 2017). As Ladyman and Ross (2007) rightly point out, the fact that evolution by natural selection is a truth-tracking process does "not imply that our everyday or habitual intuitions and cognition are likely to track truths reliably across all domains of inquiry … Proficiency in inferring the large-scale and small-scale structure of our immediate environment, or any features of parts of the universe distant from our ancestral stomping grounds, was of no relevance to our ancestors' reproductive fitness. Hence, there is no reason to imagine that our habitual intuitions and inferential responses are well designed for science" (Ladyman & Ross, 2007, p. 2).

In other words, our evolved, intuitive way of thinking is reliable when it comes to dealing with problems that were relevant to the survival of our ancestors, such as "Where will this falling rock land?"; "Is this plant edible?"; "Can I trust this person?"; and so on. It is not reliable when it comes to representing the fundamental properties and small- and large-scale structures of the world. The same cannot be said for logic and mathematics. These frameworks of thought are not innate, not content-rich, not domain-specific, and not tailored to solve particular problems in particular contexts. To the contrary, they are culturally developed, formal, general-purpose frameworks, suited to map structural relations consistently in widely diverging contexts (think of the applicability of mathematics in diverse areas such as paleontology, particle physics, and economics).

While there is no a priori guarantee that logical and mathematical representations map actual relations in these domains (i.e., that they pick out real quantitative variations and relations in the world), skeptical worries can be strongly attenuated by considering both the origin of these representations (I propose that as formal, culturally developed cognitive artifacts, they are not subject to evolutionary skeptical worries) and their effectiveness (as Wigner, 1960 famously claimed). At the very least, it should be obvious that if we have any hope of representing real structures of the external world, it is because of these powerful cognitive artifacts, not because of the hopelessly contingent and limited set of "intuitive ontologies" provided to us throughout our evolution in the service of survival and reproduction. The rather limited goal of keeping an organism out of harm's way and directing it toward the necessary resources in a particular ecological niche does not require a working model of the world that unravels its fundamental structure and properties.

Given these considerations, a structural realist stance seems warranted. I am, however, aware of the problems posed by such a position. These problems range from difficulties in distinguishing form from content (Psillos, 1995) to difficulties in taking a realist stance regarding relations without committing to such a stance regarding the relata (Chakravartty, 1998; Morganti, 2004; Psillos, 2001), to the fact that structural realism does not always seem to fit so well with sciences other than physics (Gower, 2000). As I am not defending a particular position against rival positions, I can ignore these challenges.

4.1.2. The anti-realist challenge: What about alien scientists?

An interesting consequence of casting an evolutionary light on the human cognitive apparatus and its output is that doing so requires us to concede to a sort of biological relativism. The human mind is not the disembodied seat of universal reason but a biological organ with a particular *modus operandi* and limits. The way that human animals process information is therefore not necessarily the only possible way of processing information. We have to admit that there is a possibility for what Clark (1986) called alien epistemologists or scientists. According to Clark, an "interesting consequence" of evolutionary epistemology is that we must accept the possibility of alien epistemologists working successfully with a different model of our "common reality." He argues that "the ideal limit of human scientific inquiry is still not the only possible 'correct' representation of reality even if relative to our cognitive constraints and observational access there are no visible alternatives" (Clark, 1986, p. 158).

This line of reasoning may seem to give rise to an anti-realist position, and, in fact, a number of philosophers – most notably, Thomson (1995) – have taken this road. According to Thomson, "we must admit that this mind-independent world may not resemble our representation of it, any more than a frog's or a Martian's representation (if such there be) resemble each other, or ours, or the world itself" (Thomson, 1995, p. 179). The idea is that, given that we understand the world through a particular, evolved cognitive apparatus (a contingent, evolutionary product), we have no reason to assume that its output represents the world in an objective and therefore accurate fashion.

While these concerns are legitimate with regard to our "intuitive ontologies," we have, as I have pointed out, transcended this contingent, inherited worldview in modern science. A strong skeptical stance toward modern scientific theories – or at least their structural part – is therefore not established by merely grounding our cognitive apparatus in a contingent evolutionary process. This is not to say that we humans have shaken off all constraints imposed on our thinking by our biological brain, but merely that we are (in contrast to all other animal species on this planet) no longer bound to the manifest worldview which evolution granted to us (Vlerick, 2012).

Contra Thomson (1995), I would argue that our modern scientific representation of the world should not be put on par with a frog's Umwelt as a mere contingent species-specific perspective. Nevertheless, whereas there are good grounds for claiming that our scientific representations represent the world in a more objective and complete fashion than do the perspectives of other species or even our own intuitive perspective, this still does not establish that we stumbled upon the only possible way of accurately representing the world. It does not dismiss the alien-scientist hypothesis.

Given these important evolutionary considerations, the debate between realists and anti-realists seems to be about the notion of correspondence. Evolutionary anti-realism – a strong skeptical position with regard to the output of our cognitive faculties, including our best scientific theories – is upheld by a very strong criterion of correspondence. It adheres to what Goldman (1986) calls the "mirror metaphor" of correspondence, which holds that for every state of the world, there is but one corresponding representation. The fact that alien scientists could, in principle, come up with a different (and, possibly, to us unintelligible) model of the world therefore undermines our hopes that our representations could be the only corresponding representations of the world. We are but one particular kind of cognizer, and claiming that our way of representing the world is the only true way seems hopelessly and unjustifiably anthropocentric.

However, we do not need to uphold such a strong criterion of correspondence in order to adopt a realist stance. Our representations can be right or wrong given the state of the world, even if different kinds of representations are possible. Just as a tree can be represented in a drawing, a verbal description, or in a sequence of binary code, there is no reason why the world could not be accurately (or erroneously) represented in different ways.

Goldman (1986), in this regard, proposes to substitute the mirror metaphor of correspondence for the metaphor of "fittingness," in the "sense in which clothes fit a body" (Goldman, 1986, p. 152). This metaphor allows for the "categorizing and statement-creating activity of the cognizer-speaker" while at the same time "capturing the basic realist intuition that what makes a proposition or statement true is the way the world is" (Goldman, 1986, p. 152).[6] By adopting Goldman's criterion, we can adopt a realist stance while also acknowledging that human theories (and the cognitive artifacts of logic and mathematics supporting them) might not constitute the only way to represent the world.

In general, whether we fall in the camp of the realists or the anti-realists depends crucially on the notion of correspondence to which we adhere. A strict mirror correspondence points us toward the anti-realist camp, while the looser metaphor of fittingness points us to the realist camp. As such, there is no a priori reason for adopting either criterion. However, from a naturalized perspective, where knowledge is not viewed as the product of universal laws of reason but as emerging from the inquiry of a particular type of cognizer with a particular set of interests and problems, a looser criterion of correspondence seems more suitable.

4.2 Entity component

4.2.1. The case for anti-realism: The illusion of objects

Entities and objects are species-specific constructions helping us to navigate our environment in our day-to-day existence. Seeing the world as empty space filled with objects is an evolutionary adaptation to the particular environment and scale we inhabit. The world to which natural selection attuned our perceptual and cognitive faculties is the world of medium-sized dry goods. It did not, as pointed out, endow us with intuitions about the physical world to track the structure of the microscopic realm (which explains why scientific theories about that realm – such as quantum physics – often strike us as remarkably counter-intuitive).

There is no reason to assume that the unobservable microscopic realm is made up of these evolutionarily useful but ultimately contingent species-specific (visual) constructions which make up our manifest world-image. Therefore, it is safe to assume that these visual models of unobservable entities do not mirror the microscopic world. They are the product of how our minds and senses are "designed" to perceive the "macroscopic world" (the realm of dimensions we evolved to deal with) and, by extension, to imagine and represent the microscopic world.

In fact, even with respect to the macroscopic realm, our naïve, pre-theoretical notion of objecthood has been debunked. The atomic model of matter shatters our commonsense understanding of the physical world as a space filled with objects. It states that the objects we perceive are mostly empty space (they are composed of atoms which are mostly empty space) and that the space in between objects is equally composed of atoms and, thus, not fundamentally different. Ironically, however, our manifest image of the world is debunked by scientific theory, which imported that debunked intuition of objecthood (in the form of visual models of these postulated entities) to the microscopic level.[7]

We should therefore not commit to a realist stance with regard to the visual models of postulated unobservable entities that we imported from our contingent, hard-wired intuitive notion of objecthood. This notion is, as I have pointed out, shaped by natural selection, with the sole "purpose" of navigating us successfully through the particular environment we inhabit. We have no reason to accord it any kind of epistemological authority. It is a useful fiction. As Ladyman and Ross (2007) put it forcefully in their like-named book: "everything must go."

Models of postulated unobservable entities are species-specific conceptualizations that help with understanding and developing scientific theories, but they are, strictly speaking, metaphors rather than literal descriptions of the world. In other words, given our cognitive and perceptual nature, they are useful models to help us understand the "object" of our study. They provide us, as Barbour (1974, p. 33) puts it, with "a mental picture whose unity can be more readily understood than that of a set of abstract equations." They do not provide us with a picture that corresponds with the external world.

At this point, the critical reader might object that if we were to adopt the looser criterion of fittingness – as I have proposed above – this could perhaps support a realist stance with regard to postulated entities. This line of argument would state that surely, other cognitively evolved species or alien scientists could use radically different models to represent the world, but that does not entail that our particular three-dimensional, object-like, visual models could not fit and, thus – in the sense of Goldman's (1986) criterion – correspond to the properties which they aim to represent in the world.

In the case of our visual models of postulated entities, however, I do not think that the looser notion of correspondence as fittingness can come to the rescue. Whereas we can reasonably assume that our mathematical equations can capture structure (quantifiable variations and relations) in the external world, the same cannot be said for the way we model microscopic entities. Given that these models are rooted in a contingent, species-specific way of seeing and imagining the world which has proven to be fictional on a macrocosmic level (the level which we perceive), there is absolutely no reason to assume that they "fit" the unobservable microscopic level.

In contrast to structural representations couched in mathematics and logic – which are cognitive artifacts enabling us to transcend our Umwelt – vision-based representations of unobservable entities are very much a part of our contingent Umwelt (see Section 4.1). Therefore, it stands to reason that while it is warranted to hinge claims of realism on the former – albeit based on the looser criterion of "fittingness" – we should refrain from doing so for the latter. This, however, does not mean that we should get rid of such visual models altogether. As I will argue in the next subsection, they do have an important role in science.

4.2.2. Kicking the Wittgensteinian ladder

The fact that our models of postulated entities are, strictly speaking, metaphors does not mean that they do not play an important role in the development of scientific theory. Metaphors have a central role in science. They serve two major purposes. First, they give an overall understanding of the subject. As Barbour (1974, p. 33) pointed out, theoretical models (which postulate these visualizable theoretical entities) can be more readily understood than abstract equations. They bring clarity and a sense of understanding. Consider, for instance, Harvey's metaphor of the heart as a pump or Rutherford's hydrogen atom as a miniature solar system. These are undoubtedly more readily graspable than the nitty-gritty of cardiovascular mechanisms and sub-atomic theory. The second purpose of metaphors in science is to foster new insights and direct scientific research. For instance, the leading metaphor in cognitive science of the mind as a computer has brought about research which has discovered, among other things, specialized cognitive modules. Similarly, string theory brought about a series of new insights to the study of the universe.[8]

Not adopting a realist stance with regard to our models of postulated unobservable entities does not mean that we should rid our scientific theories of them. To the contrary, these mental constructs are powerful tools which can help us formulate theories, develop science, and foster understanding. To borrow from Wittgenstein's (1921) famous metaphor, they are much like a ladder we need to reach scientific understanding. Once we've reached this understanding, we must "kick the ladder away" and refrain from committing to a problematic realistic attitude toward these models.

4.2.3. A "perspectival" realist's view?

Similar considerations about the cognizer-dependent nature of scientific theorizing have brought Ronald Giere (2006) to what he maintains is a realist stance. Giere dubs it "perspectivism" or "perspectival realism." He explains his position in analogy with color vision. As Giere (2006) points out, colors are relational properties involving both things in the world (the surface spectral reflectance of objects) and the species-specific perceptual processing of the wavelengths bouncing off these surfaces. Beings with different biological make-ups (even within the same biological species, e.g., color-blind people) can process the same visual input differently. Therefore, color vision provides us with a particular, as opposed to a universal, perspective on an aspect of the world, namely the spectral reflectance of objects.

One's particular perspective is nevertheless connected to the world. While different perspectives are possible and no perspective is objective, it does not follow that our color perception is nothing more than a subjective construct. Rather, it is the result of the interaction between aspects of the world and the evolved human visual system (Giere, 2006, p. 32). The same goes for scientific observation and theorizing, according to Giere (2006). Scientific models are the result of the interaction between the aspects of the external world studied by scientists and the biological and technological tools these scientists have at their disposal in observing the world and interpreting the data they gather from observation. While scientific models do not mirror the world, they do represent the world.

In previous work, Giere (1999, pp. 214–215) has linked this relationship to the way a map represents a given terrain. There are many different possible maps for representing a given terrain (photographic, schematic, different scales, and so on). All maps are necessarily incomplete, and no map is objective – in order to be objective, it would have to be the terrain itself and thus would no longer be a map. Nevertheless, he argues, a good map represents a given terrain. Similarly, scientific models are never objective nor even complete, but they can represent the aspects of the world they model. The fact that radically different models of the same world are possible does not mean that the models we come up with are nothing but subjective constructs (Vlerick, 2017). To the extent that they are scientifically successful, these models are our "maps" of the external world.

Nevertheless, Giere (1999, 2006) emphasizes that we should not naively assume that these models mirror the external world – in the same way that maps do not mirror the terrain they represent. This is the core of Giere's perspectival realism, and it may remind one of Goldman's (1986) notion of correspondence as "fittingness." Much like Goldman did with his looser notion of correspondence, Giere adopts his perspectival realist stance to avoid holding the ultimately untenable position of objectivist realism, which states that our scientific models mirror the world, as well as the undesirable position of relativism, which states that our scientific models are nothing but socio-historical constructs.

However, while I fully agree with Giere that the structural part of a theory maps – or "fits," as Goldman (1986) puts it – the external world, I do not believe that this is the case for visual models of a theory. Such models do not connect to the world in the way that colors in perception connect to wavelengths and maps connect to the geographical features they represent. The Wittgensteinian metaphor of a ladder seems more appropriate in this context. Giere is right in pointing out that these models give us access to the world we are studying, but as I have argued above, this does not entail that they represent the world, even in a looser sense. The central role they play in our understanding and the development of scientific theory does not mean that they lay out the properties of the external world like a map lays out relevant geographical features of the terrain it represents.

5. Conclusion

Of course, these conclusions are rough-grained and tentative. They will undoubtedly – hopefully! – attract many objections. As I pointed out in the introduction, the main purpose of this paper is not to defend a particular position, but to show the relevance of a cognitive approach to the debate. Just like the proof of the pudding is in the eating, the proof of the value of any new approach to tackling a problem is in putting it to work. I consider this paper a test ride of this new approach to an old problem *and* an invitation to others to take it for a spin!

As the cognitive sciences develop, and we learn more and more about human cognition, we should get a clearer picture on the cognitive processes underlying our scientific theorizing. While beyond the scope of this paper, it would be very interesting to analyze more thoroughly how exactly mental imagery shapes our scientific theorizing. Moreover, as it becomes clear that cognition is, to an important extent, embodied, it would be equally interesting to look at the different ways in which the embodied aspects of cognition affect scientific theorizing. Finally, and most importantly, we should take into account the various ways in which we scaffold and distribute cognitive tasks in scientific research by making use of technological instruments and other people. This is an absolute game-changer. It radically enhances human cognitive abilities. When thinking about the justification and scope of scientific theories (or components of such theories), we cannot turn a blind eye to this defining feature of human cognition (see Vlerick & Broadbent, 2015; Vlerick, 2014; Vlerick & Boudry, 2017 for such attempts). The cognitive sciences are moving at a fast pace. The time is ripe to take a cognitive perspective on central issues in the philosophy of science, such as the question of scientific realism.

In this paper, it should be clear, I do not pretend to resolve a debate; I hope to start one.

Notes

1. I will introduce the different kinds or dimensions of realism in the following section.
2. Note that what I'm proposing is not a sociological perspective on scientific knowledge which also focuses on the theorizer. While the former takes into account the cultural and historical factors underlying scientific theorizing and typically promotes a strong anti-realist position, my approach will focus on the cognitive processes (i.e., the brain processes) involved in theorizing about different aspects of a theory.
3. A notable exception is Ronald Giere, who introduced a cognitive approach to the philosophy of science in general (Giere, 1988) and, more recently, used such an approach to defend a position in the scientific realism debate, namely "perspectival realism," which I discuss below (Giere, 2006). (For another exception, see Ladyman & Ross, 2007, Chapter 1.)
4. The problem is described by Tversky and Kahneman (1983) as follows:Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.Which is more probable?A) Linda is a bank teller.B) Linda is a bank teller and is active in the feminist movement.The majority of people presented with this problem choose option B. However, probability calculus tells us that the probability of B – which is a subset of A – can never be higher than the probability of A.
5. Recently, Weisberg (2013, p. 46) has proposed a somewhat similar classification of scientific models. He distinguishes concrete models, which comprise both Barbour's experimental models – for instance, scale models of airplane wings – and Barbour's theoretical models – for instance, Watson and Crick's model of the structure of DNA –

from abstract models, comprising mathematical models and computational models, which have a mathematical structure as opposed to a concrete and "physical-like" structure.

6. Note that this looser criterion of correspondence accommodates the anti-realist worry that theory is underdetermined by evidence.
7. Note that one of the most influential accounts of anti-realism, van Fraassen's (1980) constructive empiricism, couples anti-realism regarding unobservables with realism regarding observables. The approach I take is different. It is not about elucidating the aim of science – as Van Fraassen does – in terms of achieving empirical adequacy rather than truth in explaining the phenomenal world (which is thus considered as a given and interpreted realistically), but about whether or not the (unobservable) entities we postulate correspond to external entities. As I pointed out, given that our pre-theoretical notion of objecthood is a useful but ultimately unfounded fiction which evolution endowed us with, we are no more warranted to assume that the objects we perceive daily (such as tables and chairs) correspond to real entities in the world as we are to assume that our scientific postulated entities correspond to real microscopic entities. The former we've known for quite some time, but the latter is still heavily debated.
8. Of course, the arrow points in both directions. New empirical findings give rise to new conceptual metaphors which, in turn, direct scientific research to new findings.

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