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Colors as properties of the special sciences

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Do colors exist? Although philosophers have studied this question for centuries, recently it has been the subject of a renewed burst of attention. The number of particular positions taken up in response to this question likely outnumbers the number of philosophers working on it. In general, however, two camps have formed around the issue. On the one hand, the majority of philosophers are color realists. They hold that color is a property of physical objects (e.g., Averill 1985, Byrne & Hilbert 1997c and 2003, Jackson & Pargetter 1987, Johnston 1992, Peacocke 1984, Smart 1975, and Tye 2000).[1] On the other hand, many scientists and philosophers are color anti-realists, holding that contrary to our commonsense intuitions, colors are not a part of the world around us; i.e., nothing is actually colored (e.g., Boghossian & Velleman 1989 and 1991, Cosmides & Tooby 1995, Hardin 1988, Maund 1995, and McGilvray 1994). Unsurprisingly, there is no shortage of disagreements within each group. However, in many ways, the division between realism and anti-realism is as strong as possible, since it amounts to a dispute about whether color properties even exist.

We share some sympathies with both camps. In particular, we agree with color realists insofar as we think that colors exist. But we think they exist because they are legitimate scientific constructs of the special sciences. Thus, there is room for us to agree with color anti-realists that there's currently no reason to think colors exist in the world in any way similar to how realists normally understand them to exist. We are unsure whether our view is better taken as realist or anti-realist, but we don't think much turns on either classification. In fact, we think it's questionable how many metaphysical questions about color are appropriate at our current stage of scientific understanding of the relevant phenomena. In short, although the division between realism and anti-realism appears about as fundamental to a theory of color as is logically

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[1] For purposes of simplicity, we will confine our remarks to objects, leaving to the side issues related to other apparent bearers of color, such as light emitters, volumes, and films. For similar reasons of expository ease, we will speak of properties existing and being real, without worrying about nominalist scruples.

possible, we suggest that the division isn't so important after all. According to the view we will present, a metaphysical theory of color that is designed to be of use in the sciences should be driven largely (or perhaps entirely) by considerations of what the various sciences need in order to proceed appropriately. Any further additions to such a theory are, by definition, extrascientific speculation. Although we don't rule out the utility of the latter sort of speculative enterprise, we do wish to delineate the epistemological boundary between what the sciences need from a theory of color and extrascientific speculation. As we will show, there is very little of traditional philosophical theories of color that the sciences need. If the sciences don't need much from these traditional philosophical theories, then the motivation for pursuing these latter projects must come from somewhere outside of science.

The paper is structured as follows. In section 1, we examine the pros and cons of color realism. We focus on realism since most philosophers of color are realists, and anti-realism is mainly a reaction to realism. We conclude this survey with three desiderata on a theory of color. In section 2, we begin to develop our positive view by showing that an alleged fourth desideratum on theories of color is actually mistaken. In particular, we show that color properties can be scientifically legitimate even if they are not reducible to physical properties. In section 3, we develop our positive theory by arguing that colors are properties of the special sciences. This view is developed further in section 4, where we argue that a scientific theory of colors needn't regard colors as anything more than high-level statistical constructs built out of correlations between color experiences and other phenomena. Section 5 briefly compares our view to some other views present in the philosophical literature on color. We conclude in section 6.

1. Color Realism

In this section, we examine the typical motivations for color realism and the prospects for a realist theory of color. We begin by characterizing the two main reasons for being a color realist. We then critically examine the two main forms of color realism, reductionism and dispositionalism, and we rehearse some standard but unresolved problems for each of these types. The examination of color realism will help us achieve the main goal of this section, to develop a list of desiderata on a theory of color.

Why should one be a realist about color? One reason is that color realism seems intuitively correct. In everyday life, we behave and talk as though objects are really colored.

Although perceivers are typically used to variability in the way things look to be colored, depending on the circumstances of viewing, commonsense reflection on color experience suggests that objects themselves are colored (in a more or less stable way). It seems as though instead of supposing that colors are just a by-product of the way our minds and perceptual machinery are put together, ordinary perceivers believe that, for all intents and purposes, colors are ‘stuck’ on the surfaces of objects; i.e., perceivers believe that objects maintain their color, despite sometimes looking to be a different color in certain ‘non-standard’ settings. For example, many objects that look dark blue in sunlight look almost black in dim light. Nonetheless, one would not expect most perceivers to be in doubt about the actual color of such objects; perceivers typically count such objects as dark blue and chalk up the change in apparent color to the different lighting conditions, not to any change in a quality of the objects. Of course, the much-discussed phenomenon of color constancy – i.e., the invariance of an object’s apparent color under different lighting conditions – is often brought up on behalf of color realism, as it would seem to indicate that color vision tracks a property of objects that holds constant across viewing conditions (cf. Jameson & Hurvich 1989, Tye 2000). Furthermore, it is common for some perceivers to be generally regarded as better discriminators of color. In many normal situations, almost everyone will agree that subject A is better than subject B at making fine-grained color distinctions, and that A is a better guide to the ‘true’ color of an object. If colors were just properties of experiences, it would be difficult to see why B would defer to A, since A’s color judgments would be about A’s subjective experiences, and B’s would be about B’s.

The phenomenological evidence just discussed suggests one of the two main reasons for being a color realist: a ‘massive error theory’ of color experience seems unacceptable. (A massive error theory of color experience holds that virtually all of our ordinary experiences of color erroneously represent the world, which means that we are victims of systematic and pervasive error about the color properties in the world.) Tye, for instance, voices such a sentiment when he writes

> To suppose that the qualities of which perceivers are directly aware in undergoing ordinary, everyday visual experiences are really qualities of the experiences would be to convict such experiences of massive error. That is just not credible. It seems totally implausible to hold that visual experience is systematically misleading in this way. (Tye 2000, p.46)

Massive error theories are especially repugnant to color realists who want to explain our conscious experiences of color in terms of the color properties that they claim exist in the world; e.g., externalist representationalists about phenomenal consciousness such as Dretske, Lycan, and Tye. For instance, Lycan writes,

> On pain of circularity, the Representational theory requires color realism, for it explicates color qualia in terms of the real- and (unreal-)world colors of physical objects …. One could not then turn around and explicate the ostensible colors of physical objects in terms of color qualia. (Lycan 2001, p.20)

The passages from Tye and Lycan are only two of the more straightforward statements of a connection between one's theory of experience and the ontological status of color. Similar sentiments can be found in Dretske (1995, pp.88-93), Byrne & Hilbert (2003, esp. sections 3.2 and 3.3), and Jackson (1996, p.214). Prima facie, then, it looks like a non-realist view about the metaphysics of color properties implies a massive error theory about our experiences of color, and the latter is unacceptable. So realism is right (or so the argument goes).[2]

Color anti-realism drives a deep wedge between appearance and reality that is inconsistent with commonsense reflection on the nature of color. Furthermore, it runs the risk of producing a scientifically unacceptable account of the relation between experience and the world. But there is another general reason for endorsing color realism. Should it turn out that nothing is actually colored, it's unclear how to make sense of the use of color properties in the sciences. Various areas of the cognitive sciences, biology, and even such fields as industrial engineering employ color predicates in stating lawlike generalizations about the phenomena within their domain. Thus a theory of color should make sense of, or at least not rule out, the legitimacy of color properties in scientific practice. But by definition, color anti-realism says that colors don't really exist, so color properties don't really refer to anything in the world. How could science work as it does if laws pertaining to the actual behavior of actual entities depend on those entities having properties that nothing has? Such a view of science seems deeply wrong-headed, so color anti-realism must be wrong and color realism must be right.

In short, it looks like the case for color realism is about as strong as possible: our intuitions say that colors really exist and scientific practice confirms this. What more evidence could one want? Considerations like these may be what has led most philosophers of color to be

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[2] See **author2 2003** for a sustained attack on this argument.

realists. However, despite all the evidence for realism and agreement about it, current realist theories leave much to be desired. There are well known and unresolved fundamental problems with color realism. We turn now to a brief discussion of a few central problems for the two leading types of realism found in the literature. Although the problems do not logically entail the falsity of color realism, they do suggest the need for rethinking the basis of a theory of color.

A survey of the literature shows that realist theories about color tend to be either 'reductive' or 'dispositional'. Reductive theories say that color properties are simply complex physical properties of objects, much as their size, shape or mass (e.g., Armstrong 1987, Byrne & Hilbert 2003, Jackson & Pargetter 1987, Jackson 1996, Tye 2000). On the other hand, dispositionalist theories hold that colors are dispositions to cause experiences of a particular sort; e.g., the color blue is the disposition to cause blue experiences. Unlike reductive realism, dispositionalism has it that the individuation of color properties depends on subjective facts about color perceivers (e.g., Averill 1985, Evans 1980, Johnston 1992, McDowell 1985, McGinn 1983, and Peacocke 1984).[3] We will first discuss dispositionalism about color, and then we will turn to reductionism.

One of the main worries about dispositionalist theories of color is that dispositions themselves aren't causally efficacious. Rather, it is a disposition's heterogeneous, multiply-realizable categorical basis that is responsible for an object's causal interactions with the world. Because there are so many different ways to realize a disposition, a dispositional property cannot be identified with any particular categorical basis (or finite Boolean combination of bases) that realizes it in a particular instance. This creates a problem because, as Frank Jackson and Robert Pargetter (1987) have observed, it's plausible that S sees X only if X causes (in the right sort of way) S's visual episode.[4] If this is right, it follows that a person never sees any colors. Colors may exist on this account, but we cannot see them. Thus, dispositionalist theories appear to be a form of massive error theory about color experience, much as anti-realist theories are. Moreover, by defining their subject matter so that colors become immune to scientific study, it is unclear

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[3] Of course, there are some objectivist accounts that hold that colors are objective, mind-independent properties of objects, but that it is a subjective matter which property is which color, depending on who is doing the viewing and in what conditions. Jackson & Pargetter 1987 and Jackson 1996 have such a view, and the relational view developed by Tye 2000 is in the same vein. So, for objectivists of this sort, the individuation of color properties does depend on subjective facts about perceivers, but only in part.

[4] See Tye 2000, pp.149, 161, and 167fn.2; Bradley & Tye 2001, p.471fn.6; Jackson & Pargetter 1987, p.69; Jackson 1996, p.201; and Byrne & Hilbert 2003, section 3.1 for examples of color realists who endorse the claim that any acceptable realist account of color must identify colors with the (typical) causes of color experiences.

what phenomenon dispositionalist theories are even characterizing. If dispositionalists are right about color, then perhaps philosophers and color scientists have actually been studying something else, ‘schmolor’, which is something we see and that can figure into scientific laws. In that case, it would be reasonable to conclude that schmolor is what we were interested in all along.

The other common route to color realism is the reductive approach. A reductionist identifies each color with a particular physical property of an object, so it’s clear how colors are realized. Since physical properties can interact causally with perceivers, the reductionist can maintain that we see colors and that colors are legitimate scientific properties (cf. Tye 2000, pp.148-150 for discussion of the kinds of theory a non-dispositionalist realist has to choose from, as well as an argument for why reductive physicalism is the only plausible option). However, a major difficulty for reductionism comes from the scientific literature about the nature of color. The problem is that there appear to be too many possible physical properties that can be causally responsible for our experience of any particular color. Take, for example, the physical causes of experiences of a determinate shade of red, say, red_{23}. Whether one considers the microphysical structure of objects (<u>microphysical realism</u>) or – the more common option – a higher-order property such as spectral reflectance (<u>reflectance realism</u>), it turns out that a heterogeneous disjunction of properties can cause experiences of red_{23}.[5] In the case of microphysical realism, it is well known that the microphysical causes of color experiences vary widely, depending on the constitution of the perceiver, the physical structure of the object perceived, and the conditions in which the object is viewed. Thus, the various microphysical structures of things that look to be colored red_{23} needn’t have anything interesting in common in order to produce their shared effect on perceivers (cf. Nassau 1980, p. 28 for a taxonomy of the physical causes of color). For reflectance realism, a similar problem arises with metamers. Metamers are stimuli having (possibly very) different spectral reflectance distributions that produce the same experienced color. So a theory that identifies colors with their spectral reflectance profiles will posit a great

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[5] Philosophers who have advocated identifying colors with microphysical properties include David Armstrong (1987), J.J.C. Smart (1975), and Frank Jackson & Robert Pargetter (1987; Jackson 1996). Reflectance realists count Alex Byrne & David Hilbert (1997c, 2003; Hilbert 1992), Fred Dretske (1995), and Michael Tye (1995 and 2000; Bradley & Tye 2001) among their number.

many more colors than there seem to actually be.[6] (For some further objections to color realism. cf. Boghossian and Velleman 1991, Hardin 1988 and 1992, Thompson 2000.)

This brief survey of color realism helps to bring out three plausible desiderata on a theory of color. The first desideratum is given in (D1):

(D1) A theory of color should render (or at least be consistent with) the scientific study of colors as legitimate.

One of the main objections to anti-realism is that it's unclear how such a view is consistent with the scientific study of color. Similarly, dispositionalism has trouble providing a causal basis for colors. But since there are productive areas of scientific research into color, this desideratum seems non-negotiable. It is worth noting at this point that one of the more significant claims we hope to develop in this paper is that much of the debate in the color literature between realists and anti-realists is based on an ill-conceived demand that, for realism to be true, there must be a neat, categorical mapping of colors onto physically-specifiable kinds. We will argue (particularly in section 4) that such a way of framing the realist/anti-realist distinction is grossly out of step with how high-level properties are typically treated in the special sciences, thereby making a great deal of the philosophical discussion of the reality of color scientifically irrelevant. We will not speculate about why this fundamental flaw has gone unnoticed for so long.

The second desideratum comes from the problems for dispositional and reductive realism:

(D2) A theory of color should provide a metaphysical/scientific basis for the nature of colors that allows for the colors to be correctly individuated.

Both dispositionalism and reductionism appear to violate (D2). Dispositionalism individuates the colors correctly, but there doesn't seem to be any way to specify these colors in a metaphysically or scientifically appropriate way. Reductionism, on the other hand, does supply a physical

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[6] It's also worth noting that spectral reflectance properties are dispositions to reflect a certain percentage of incident light at each wavelength or over particular bandwidths. Thus, such theories inherit all the difficulties that are attached to dispositional theories of color. **author2 2003** has discussed the shortcomings of Tye's 2000 attempt to work around the problem of the dispositional nature of spectral reflectances. See Byrne & Hilbert 2003 and Bradley & Tye 2001 for recent attempts to handle metamerism within color realism.

specification for colors, but this specification is unable to individuate the colors correctly. Despite these difficulties, (D2) is non-negotiable, because correctly individuating colors along scientifically respectable lines isn't optional.

The final desideratum requires some work to clarify. It concerns the role of our intuitions about color. Ideally, a theory of Xs would perfectly match our intuitions about Xs. However, it is well known that this often doesn't happen in science: e.g. contemporary physics shows that our intuitions about space and time are wildly incorrect. Thus it would be unfair to demand that a theory of color accord with all of our intuitions about color. Nonetheless, it is reasonable to ask that a theory of color explain some of our very deeply held intuitions about color. After all, if a theory of Xs fails to address our most fundamental beliefs about Xs, then it becomes unclear what makes it a theory of Xs, and not a theory of something else. Such sentiments appear to motivate two widely held beliefs about color. The first belief, which we accept, is given in (D3):

(D3) A theory of color should explain how we have color experiences.

We take (D3) to be almost a truism. After all, a philosophical theory of color contains a major gap if it explains what colors are but leaves it entirely unclear how we ever experience these colors. (D3) captures an important assumption behind Jackson and Pargetter's anti-dispositionalist argument discussed above. They argue that a theory of color that implies we don't see colors is unacceptable. A major reason for this unacceptability is that the resulting theory leaves the nature of color experience unclear, thus violating (D3).

Our intuitions also motivate another belief about theories of colors. Prima facie, it seems a theory of color should rule out the possibility of a massive error theory of color experience (cf. the quote from Tye above). After all, a theory that simply denied that there was any truth to our color experiences would seem to be a theory of something other than what we meant to discuss when using the word 'color'. When you look at a red apple, you have a certain chromatic visual experience, and a theory of color that denied that there was any property in the world that you were seeing would appear to simply deny the overt visual phenomena. A theory of color – in the sense of 'color' that is of interest – should explain what we see when we see red, instead of simply denying that we see anything. Despite the intuitive plausibility of this idea, we do not believe that a theory of color must rule out massive error theories of color experience, when 'massive error' is understood as it typically is in the philosophy of color literature. In the next section, we begin to develop our positive view of color by showing how a kind of massive error theory can be compatible with our basic intuitions about color. We complete our positive account in section 3.

Before showing how some kinds of massive error theories can be acceptable, a word is in order about the qualification 'when "massive error" is understood as it typically is in the philosophy of color literature'. Notice that if a theory entails that colors do not exist, then it is a massive error theory. Thus, a massive error theory depends in part on a criterion of the existence of color properties. As our overview of the literature suggests, philosophers of color frequently assume that if a color property is not reducible to some physically specifiable 'natural' property, then that property does not exist (e.g., Hardin 1988, Jackson 1996, Tye 2000). But as we argue in section 2, this is an incorrect condition on color property existence. Ultimately, reliance on this condition is the source of much confusion about color. We will later see that with a more plausible condition in its place, many of the worries about color realism and anti-realism simply disappear.

2. The acceptability of the irreducibility of color properties

As just discussed, let us assume for the moment that color properties exist only if they are reducible to physical properties and that if color properties don't exist, then a massive error theory is true. Assume that color properties aren't reducible to physical properties. We now show that the resulting massive error theory may nonetheless satisfy (D1) – (D3).

According to our assumptions, there are no colors. The world is achromatic, but our ordinary visual experience represents it as being filled with colors. In such a case, (D2) is trivially satisfied, but (D1) looks unsatisfiable. If there are no colors, how could the scientific study of them be legitimate? Color experience is only a persistent illusion that humans and other creatures with chromatic vision cannot shake. If color experience is massively in error, then color experience should be of little help – and perhaps a hindrance – in how we make our way through the world, since our reasoning and beliefs grounded in color experience would be in conflict with the actual nature of things. Similar considerations suggest that (D3) should be hard to motivate, too: if there are no colors, then how could we have color experiences?

Despite the apparent initial difficulty in grasping how color vision in an achromatic world could have the central role in our mental lives it does, further reflection on the benefits color vision provides removes this obstacle. Even if the world is achromatic, color vision gives creatures a number of advantages in dealing with the demands of daily life. In fact, these advantages are so significant that it's not implausible that color vision was selected for, even if it were to turn out to be a source of systematic illusion. Consider, for example, how color vision influences a creature's interactions with its environment. Crucially, even if there are no colors, there still may be relations holding with statistical regularity between color experiences and physical properties of the objects of these experiences. (Obviously, statistical correlations between types of phenomena can be extremely strong, despite having (infinitely) many exceptions.) For example, the physical structure – e.g., chemical composition, crystal structure, density – of objects determines the wavelengths of light they reflect, absorb, and allow to pass freely. Thus a wavelength detection system that is capable of exploiting regularities of wavelength phenomena in its environment could prove highly valuable to a creature, as the wavelength regularities themselves would be a sufficient basis for further processing that yields biologically significant information that the creature can use to successfully make its way through the world, so long as the operations performed on the acquired wavelength information have the right sort of built-in assumptions about relatively stable features of the creature's environment. None of this requires that the world actually be colored.

Additional detail can be added to these points. Plants containing chlorophyll appear green because chlorophyll reflects light from the middle part of the visible spectrum while absorbing light from the long and short wavelength ends of the visible spectrum. Rubies appear deep red with a slight purplish cast due to the immersion of a chromium ion in a strong electric field that results from the clustering of oxygen ions, which leads to a strong emission of light from the long wavelength part of the visible spectrum and a weaker emission of light from the short wavelength region of the visible spectrum (Nassau 1980, p.11). Furthermore, it's plausible that the physical structures of objects that are responsible for how they appear chromatically are often themselves tied to other important properties of that object. For example, the phytochemical lycopene is responsible for the characteristic red and pink appearance of fruits such as watermelon, tomatoes, and grapefruit, and it is also beneficial to many creatures that ingest it (Fraser et al. 2002, p.1093). Ceteris paribus, creatures that lack the appropriate kind of color experiences tend to perform rather poorly at disambiguating ripe fruit from dappled backgrounds. Thus, it is unsurprising that tropical fruits, which visually announce their ripeness with vivid yellow and orange hues, are primarily consumed by trichromatic humans and other

Old World primates, who are well-endowed—perhaps uniquely so—to discriminate the ripe fruit from both its green surroundings and non-ripe fruit on the basis of their color experiences (cf. Mollon 2000, pp.23-25; Nathans 1999, p.304; Snodderly 1977, pp.270-272; Thompson 2000, p.177; Yokoyama 1997, p.324). As another example, consider the rush of blood to the dermis that accompanies sexual arousal in many species. While this redirection of blood flow to the body's surface is typically related to commands from the brain to increase respiratory and circulatory activity in preparation for intercourse, it also provides a signal to potential suitors that the creature is ready to mate, as the reflectance characteristics of certain chemicals in the blood (viz., hemoglobin, bilirubin, and beta-carotene) give the aroused creature's skin a pronounced chromatic appearance. In sum, even in an achromatic world, substantial adaptive value could easily come from a pervasively deceptive color vision system. Although a species might falsely represent parts of the world as being colored, the causes of these false representations would themselves be linked – with enough statistical regularity to be useful to members of the species – to properties in the species' ecological environment that do matter to its evolutionary success. Indeed, the false information generated by color vision may well be quite useful to the creature, if it enables the creature to rapidly acquire and manipulate relevant types of information about its environment.[7]

In short, even if color experience is not veridical, there may still be important statistical regularities between (i) how things chromatically appear, (ii) the physical structures that cause (i), and (iii) other beneficial or interesting properties of objects. As long as these regularities hold robustly enough to support a useful regularity between (i) and (iii), color vision will supply useful information about the environment.[8] Using that information, creatures of this type can build strategies and take actions that contribute to its continued well-being and adaptive success.

The statistical connections between (i) and (ii) insure that a given creature will (<u>ceteris paribus</u>, of course) have a certain color experience CE when it sees the physical structure P. However, it does not follow that the creature will have CE whenever it sees any physical

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[7] Fodor (1983, p.71) raises the point about "[trading] false positives for speed" in arguing that there are no <u>a priori</u> grounds for thinking an indicator system must generate veridical information in order to be useful. Don Dedrick 1995, C.L. Hardin 1992, and **author2 2003** have extended this point to the adaptive value of massively erroneous color experience.

[8] Notice that these advantages remain even if there are many exceptions to the regularities mentioned above. E.g., the correlation may not hold at all outside of the creature's ecological niche, there may be occasional dangerous exceptions to it within the niche, and the relation between (i) and (ii) may not hold under certain unusual conditions (e.g., ill health, poor lighting, and other rare effects due to chance alone).

structure P' that produces CE in some other type of creature. In particular, just because fruit bats experience a certain shade of red when they see ripe berries, it doesn't follow that they also experience that same shade of red in every other object that causes humans to experience that shade of red. Which correlations exist for which creatures are straightforward empirical matters. Furthermore, since (as we are presently assuming) there are no colors, some types of creatures (e.g. humans) may have CE if and only if they are in some general type of circumstance that is itself not physically reducible. But even so, there still remain a great many scientific questions to be asked. For instance: Within a given species, what types of physically specifiable structures in the species' normal environment typically cause CE? How does a creature's visual system produce the various color experiences CE_1, CE_2…, that it can have? What visual processes are similar in having either CE_i or CE_j, and what processes are used by only one (and to what degree, etc.)? We can also design tests to study the conditions under which a species judges CE_i to be more similar to CE_j than CE_m and CE_n are, thus generating a similarity space for that species. We can then study the correlations between the similarity spaces produced by different species, and we can look at various physical circumstances in which one species has two color experiences where another only has one. In short, the science of colors can proceed as it does in the actual world.

To flesh out the ideas of the last paragraph, consider some of the actual uses of color in a field like biology. Evolutionary and molecular biologists use color properties in their explanations of the widely varying morphological complexity of the spectrally sensitive receptors (i.e., cones) of different species. For instance, the oil droplets contained in the cones of (typically diurnal) vertebrates such as birds and newts act as cut-off filters to wavelengths below a certain threshold, thereby shifting their color space to the longer wavelength regions of the spectrum (Yokoyama 2000, p.388). Ethologists and population biologists employ color properties when explaining phenomena such as camouflage, mimicry, and sexual display (Yokoyama 1997, p.331; cf. also Gruber 1977, 185-187, 225-227; Hinton 1973 97-104; Wickler 1968 51-62, 169-171). Clearly, a vast number of other examples of this sort could be presented. These uses of colors seem about as legitimate as anything in science, regardless of whether colors are reducible to physical kinds.

Further support for the evolutionary story told above comes from the fact that there is no empirical reason to suppose that just because two species have color vision, their visual systems are each tracking the same properties in the world. Thus the distal causes of color experiences turn out to be far more heterogeneous and multiply realizable than color realists typically consider. Basically, the color vision system of a chromatically-sighted creature serves as a wavelength detector, because the receptors that provide the input to any creature's color vision system are maximally sensitive to certain wavelengths. However, that is far from sufficient as a specification of the biological function of the creature's color vision system. In different species, color vision carries out different functions. That is, the way in which wavelength information acquired by light striking wavelength-sensitive photoreceptors is processed to extract further information about a creature's environment varies, depending on how natural selection shaped the particular kind of creature's color vision machinery in response to the environmental challenges it (and its evolutionary ancestors) has faced. To get an idea of the ways in which the function of color vision can vary, consider the following passage from Evan Thompson:

> … for fish, the hypothesis is that color vision serves to heighten the contrast between foreground objects and the background aquatic space light (Lythgoe 1972, 1979; Levine & MacNichol 1979, 1982), and to detect spectral emittances in the case of bioluminescent organs (Bowmaker 1991). For birds, the hypothesis is that color vision serves not only in the detection of SSR [sc. surface spectral reflectance], but also in orientation and biological signaling (Thompson et al. 1992; Varela et al. 1993; Bennett & Cuthill 1994; Bennett et al. 1994). For the honeybee the hypothesis is that color vision serves primarily in the detection of flowers and in orientation at the hive entrance (Menzel & Backhaus 1991). For primates, the hypothesis is that color vision facilitates object detection and recognition, as well as the segmentation of the visual scene (Mollon 1989); it has also been argued that color vision facilitates the perception of illumination conditions in their own right (Jameson & Hurvich 1989). (Thompson 2000, p. 166)[9]

Thompson concludes that there is no single type of physical property that it is the biological function of color vision to detect. In explaining both the biological basis of color vision in different creatures and the cognitive operations that are performed on the information generated by different creatures' color vision systems, scientists will have no choice but to liberally employ color properties. Furthermore, there will be physical underpinnings to all the higher-level properties and events that fall under the scientists' explanations. Nonetheless, given the variation in the properties that are tracked by different creatures' color vision systems and what we know about the open-endedness of the physical realizations of the causes of color experiences in humans, there is no known way of reducing the causes of a particular color experience to a

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[9] For further discussion of empirical data supporting the hypothesis that birds (and other creatures such as newts) make use of specialized photoreceptors (e.g., oil droplets containing particles of magnetite (Fe_3O_4)) for magnetoreception and magnetic orientation, see Deutschlander et al. 1999.

physical kind. The lack of a physical reduction, however, doesn't undermine the scientific legitimacy of these properties.

So far, we have shown how the physical irreducibility of colors (coupled with the assumption that to be is to be physically reducible) need not conflict with desideratum (D1), (D2) or (D3). In fact, we argued that in a world that differs from the actual world at most in that colors aren't physically reducible in it, (D1), (D2), and (D3) are satisfied. We did this by showing that creatures in such a world could plausibly have evolved to have the same color experiences that they have in our world. The fact that they do have such experiences is a sufficient basis for reconstructing the scientific study of color. In the next section, we will further develop the view characterized here into a positive theory of color. Obviously, satisfying (D1) – (D3) doesn't necessarily make a theory of color correct. In particular, despite what we have shown in this section, something still seems to be correct about the intuition that massive error theories are unacceptable. The brute feeling here is that even if there are infinitely many physical realizations of some determinate shade of red, they nonetheless all have something in common, namely, they're all this shade of red – or at the very least, they all cause a given person to have an experience of this shade of red. A massive error theory appears to deny or ignore this fact. So something, the argument concludes, must still be really wrong about massive error theories. Despite what we have shown in this section, we endorse this intuition and we show in the next section that our theory accommodates it.

3. Color properties as properties of the special sciences

We think that colors are best thought of as properties of the special sciences. We begin by reviewing the general notion of a special science property, and then we use it to fill out our theory of color. The resulting theory helps to expose the truth behind the lingering intuition that massive error theories really are unacceptable, contrary to what section 2 appears to have shown.

As Fodor (1975) has famously argued, 'special' sciences are those fields like biology, geology, economics, cognitive psychology, and linguistics, for which there is no obvious way to reduce the fundamental properties and relations they use to finite, non-open-ended, and 'natural' properties and relations of physics. Although the fundamental properties of chemistry have been brought into line with contemporary physics (Thackeray 1970), it is entirely unclear how this sort of unification might be had for any of the special sciences. There appear to be just too many ways to physically realize such properties as that of being a mating strategy, or an echolocator, or a speaker of a head-initial language. We can, of course, agree that e.g. any given instantiation of a mating strategy is nothing over and above the physical elements and physical properties that realize it. However, there may be too many different ways to realize mating strategies for it to be plausibly supposed that such properties can be reduced to physically 'natural' properties. Instead, it looks like the only hope for a physical reduction of one of these properties would have the form:

(1) x is an echolocator iff x has complex physical property P_1 or P_2 or … or P_n or …

If there are infinitely many ways to physically realize an echolocator, then the disjunction in (1) will be infinitely long. But even if there are only finitely many ways to realize an echolocator, (1) may be so arbitrary and odd from a physical standpoint there is no reason to treat it as a 'natural' property of physics, in much the way that being a glick is not a natural property of any science. (Glicks are horses with short tails, or things containing molten iron iff the sun is out, or pears.) In either case, it may well be that the only thing all and only the echolocators have in common is that they are echolocators. (The issue of multiple realizability has, of course, received a great deal of attention in the last 30 years; e.g., Demopoulos 1987, Sober 1999, Polger 2002, Batterman 2000. As we explain immediately below, we are not committed to any particular stance on this issue, although we do believe that it raises a worry for standard forms of color realism.) But regardless of whether or not they are reducible in this way, echolocators earn their scientific respectability by the useful explanatory and predictive work they do in biology. Whether the property of being an echolocator is reducible to physical properties is simply an orthogonal issue. Thus, echolocators may exist even if the property of being an echolocator isn't reducible to physical properties. This last point should be emphasized. Whether or not a given property counts as real or not does not depend on whether it can (in principle or in practice) be reduced to some 'natural' physical property. Rather, the justification for a property's being real typically comes from the work it does in our best scientific theories. If a property plays a crucial role in our best scientific theories, then we are eo ipso justified in treating it as real. Thus, epistemology drives metaphysics: our best theories typically determine what things (properties, relations, etc.) we consider to be real.

It’s worth noting that the argument just offered applies more widely than to just the special sciences listed above. It also applies to quasi-mathematical notions. Consider the property of being something that computes addition. It may well be that the only feature found in all and only the actual and possible physical realizations of addition computers is that they compute addition.[10] The fact that the computation of addition cannot be realized by a single natural property of physics does nothing to undermine the scientific respectability of this notion. (For more discussion of this issue, cf. Demopoulos 1987.)

As we saw in section 2, color properties play an important role in various scientific disciplines even if they are irreducible to physics. The fact that colors are used this way in the sciences, we claim, is enough to render colors scientifically legitimate, much as the property of computing addition is scientifically legitimate. Thus, colors exist as a part of our best overall scientific taxonomy of properties in the universe. By treating colors as properties of the special sciences, colors turn out to be real in a very important sense. Colors exist as scientific constructs because of how the world is put together; they are not in any way a spooky challenge to the idea that physics is bedrock science. By seeking a more robust connection between colors and physical properties than the fact that every instantiation of a color property is an instantiation of physical properties, reductive color realists have made a mistake akin to trying to reduce to physics the behavior of market economies or the production of new species. For a similar sentiment developed in a very different way, cf. Broackes 1992.

It should be clear that we do not endorse the assumption toyed with in section 2, that a property exists only if it is reducible to physics. Such an assumption may be correct, but then again, it may not (cf. Wilson 1986, Batterman 2000). More importantly, the criterion of reducibility simply doesn’t reflect how the ontology of science is justified in actual practice. In the sciences, to be is to be part of our best scientific theories. Whether or not something is reducible to physics typically plays no justificatory role. Using this new criterion of existence in place of the reducibility criterion also helps to explain the intuition that something is wrong with a massive error theory of color experience. In section 2, we showed that massive error theories can be acceptable when we assume that color properties exist only if they are reducible to

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[10] As Demopoulos (1987, 83) observes,

> if we have different architectural environments and implement the same program in each of them, it is not unreasonable to expect that there will be no single set of physical laws which cover all the implementations. Adjacent machine states in one environment may be subject to different laws than their ‘counterparts’ in another environment. Thus there is no question of reducing the program to one type of physical behavior, and hence there is a clear sense in which the computational behavior is not specifiable at the level of physics.

physics. But we do not appear to get the same result if we assume instead that color properties exist only if they are part of our best overall scientific theories. Leaving aside many issues and qualifications, a very rough argument for this claim is as follows. Assume a massive error theory is true. Either color properties exist or they don't. If color properties do not exist, then they are not part of our best scientific theories, which is contrary to fact. So color properties do exist. By our assumption, however, color experiences are massively in error. But a major source of evidence for a scientific theory of color comes from our reports of our color experiences. So if our color experiences are massively in error, then so are our reports about them, which means that our best scientific theories of color have been constructed around these erroneous reports. But these scientific theories are what largely determine which properties we are talking about. Thus our best scientific theories contain lawlike descriptions of the behavior of some deceptive property, 'schmolor', which is different than color. But now it appears that color, whatever it is, has gone undiscovered by science, although some close relative, schmolor, appears to satisfy enough of our scientific inquiries into color to pass as color. Schmolor properties, but not color properties, are part of our best scientific theories. So color properties do not exist, a contradiction. Thus a massive error theory is false. There is more that could be said about this argument, but it appears to be basically correct.[11] Assuming it is, we see why some doubt remained about the acceptability of massive error theories. With a proper criterion of property existence in hand, massive error theories really are unacceptable. As we just saw, a massive error theory works by convicting our best scientific theories of massive error, which is an intolerable result.

A review of the philosophical literature on color makes clear that the battle lines between realism and anti-realism have been drawn with little regard to what use the sciences make of color. The participants in the debate agree that the existence of color requires that it be reducible to some physical property, whether higher-level or microphysical. On this way of conceiving the debate, the only matter to be resolved is whether the necessary reduction can be had. In a recent paper in which he criticizes Michael Tye's reflectance realism, C.L. Hardin concludes by stating

> [color] realists hold that the world contains both spectral reflectances and experiences of color. Color antirealists agree, and point out that spectral power distributions and color experiences are jointly sufficient to

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[11] Notice, for instance, that the argument is not an a priori refutation of skepticism. Rather, the argument proceeds by begging the question against radical skepticism. As scientific practice, we think this move is very standard and plausible. Everyone can admit radical skepticism might be true; there could be such strong evidence from other sources that would lead the best overall theory of color to be, e.g., a massive error theory of human color experiences. However, we know of no remotely plausible evidence for this suggestion.

> explain the gamut of chromatic phenomena. We need not invoke the colors of commonsense realism at all. So why should we include them in our ontology? (Hardin 2003, pp.201-202)

Our reaction to such a comment is that it reveals an overly restrictive understanding of realism; viz., one that demands a reduction to physics. According to this thinking, if colors don't reduce to some physically-specifiable natural kind, there is no need to include colors – as commonsense understands them to be, which is as properties of the surfaces of objects – in our ontology. But we have argued that reducibility is not relevant to color realism and we have observed that color properties <u>do</u> play a role in explanations and generalizations in some branches of the special sciences. As should become clearer in the next section, we have every reason to take seriously color as a legitimate subject of scientific inquiry, despite what Hardin claims about spectral power distributions and color experiences (more accurately, the facts about how our minds are constructed that are relevant to color experience). We do not deny that whether or not color reduces to spectral reflectance (or any other candidate physical property) is an interesting issue. However, it is not the litmus test for the reality of color. Conclusions about the reality of color should be drawn from what we know about color's role in the explanations and predictions of the sciences. <u>Pace</u> what is implied by Hardin's claim about what we "need not" do, colors clearly play an important role in a variety of scientific disciplines, and their scientific legitimacy is what purchases their reality.

4. Representing colors as latent variables

Given that scientific practice justifies treating colors as real regardless of the reducibility of the latter, what sort of properties should we take colors to be? Attention to the methodology of science suggests that more detail can be added to the claim that colors are special science properties. In fact, the ordinary statistical tools of empirical science allow us to articulate a theory of how colors should be regarded. First, though, it will be helpful say a bit more about color experiences.

As we've discussed, the most prominent uses of color terms in science are in laws concerning the sorts of color experiences certain creatures have and the conditions under which they have them. Similarly, philosophers routinely hold that color experiences play a critical role in the individuation of color properties. But obviously a scientist can't directly observe another creature's color experiences. Rather, she infers the presence of these experiences on the basis of behavioral data, background theory, etc. How might the inference go from overt data to an unobservable state like another creature's color experiences? In the general case, the scientist, driven by some hypothesis, begins by collecting data of various sorts, and discovers correlations between a creature's behavior and the physical type of environment the creature was exposed to in the experiment. For example, there might be a correlation between the creature showing a marked preference for – e.g., by selectively choosing – one piece of fruit over another when, holding all other variables constant, the first piece of fruit has a particular physical structure P (which makes it look red) and the second has a structure Q (which makes it look green). P and Q may not exhaust the possible physical realizations of red and green, so if the scientist is exploring whether a type of creature has color experiences of a particular sort, it would be natural to use multiple physical structures P_1, P_2,… and Q_1, Q_2,…, so that the only plausible commonality among the P_is was that they all appeared red (perhaps as measured by the judgments of various other (human or non-human) subjects), and similarly for the Q_is. If the scientist is being cautious, she would then apply some statistical technique such as a principal component analysis or a factor analysis to extract the 'latent variables' of the experimental data.[12] Latent variables are high-level statistical constructs that explain (in a statistical sense) some amount of the variance or correlations present in the data. Finally, further tests would help confirm the hypothesis that the statistical behavior of this construction is due to some 'hidden' property, such as a color experience, that is only observable via its effects on behavior. This general sort of method for uncovering unobserved structure, here in the form of color experiences of other creatures, is absolutely standard in the sciences. The posited structure always remains an empirical hypothesis, subject to further empirical exploration and (dis)confirmation. This is, we think, exactly how things should be.

One of the many advantages of such a treatment of color experience is that the resulting theory generates precise, quantitative predictions. For example, *if* (and as with all normal science, this is a big 'if') the relevant experiments have been conducted correctly, with potentially confounding elements blocked out, etc., then when properly organized, a theory of the color experiences of a certain type of creature would predict that in certain situations (e.g., paradigmatic situations of experiencing a particular shade of red), the first principal component extracted from the data should be much larger than the second. Moreover, the second principal

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[12] Principal component analysis and factor analysis are only two examples of structure-extracting techniques. For various purposes, other procedures such as multidimensional scaling and cluster analysis would be appropriate as well. Cf. below for citations.

component itself should be quite small, ideally small enough to meet a threshold criterion for representing only random variation. (If the tests were run in a carefully controlled laboratory setting, a natural psychometric situation to demand and expect would be that ‘color experience’ be measured in around twenty different ways, with much more than 90% of the variation in the data projected onto a single latent structure.) To the extent that this does not happen, there would be evidence that other processes were at work. Depending on the nature of the data collected, these other processes could indicate that different creatures track different properties (e.g., that their color experiences are organized around different properties, etc.). These same techniques can also be used to make quantitative predictions about various other sorts of behaviors, such as the degree to which a creature of a given type finds two colors hard to distinguish, and the degrees to which various types of creatures make similar discriminations. (We here only list some of the predictions a successful statistical model (or family of models) of latent variables can make. The mathematical details of the underlying techniques, while standard fare of multivariate statistics (e.g., Basilevsky 1994, Morrison 1990), are too complex to be discussed in much detail here. Roughly speaking though, the kth principal component extracted from a collection of n random variables ($k \leq n$) is that linear combination of the n variables with the maximum possible variance given that (a) the length of the vector of coefficients (i.e., the sum of the squared coefficients) is 1, and (b) for all $j < k$, the correlation between the jth and kth principal components is 0.)

The methods and techniques described in the previous paragraph are standard equipment in psychophysics, cognitive science, and many other disciplines that study the behavior of complex systems. Indeed, the techniques used are just the ones appropriate for inferring the existence of some ‘hidden’ property that is not directly measurable, and where any measurement of the effects of the property’s presence always contains the effects of other features (‘noise’) within the system. Thus, the inference to other creatures’ color experiences on the basis of their behavioral data is just the sort of thing that statistical methods of data analysis are designed to help us with.

In short, the inference that color experiences exist can go in three stages. First, data is collected and organized. Second, the data is analyzed, using statistical techniques for extracting latent variables, and the hidden properties (e.g., common factors, principal components, etc.) underlying some relevant subset of the data are uncovered. Finally, the hypothesis is formed and tested that what the latent variables represent are color experiences of various sorts. Of course, all this is not meant to suggest that that color science need actually proceed in this fashion. In the actual history of science, scientists may have approached some of these questions with strong background assumptions that made it easy to infer color experiences from the data. The strategy outlined here would be particularly appropriate if there were no strong background assumptions. Thus, it is a characterization of how scientists *would* characterize color experiences within their theories if they were called upon to justify the existence of color experiences.

Once we have justified an ontology of color experiences, with their various empirically discovered quirks and interrelations, we can then use such phenomena, along with other phenomena such as physical characterizations, reflectance profiles, etc., to uncover a scientific view of colors. The methods here are similar to those used above for color experiences. The crucial step involves combining the various data we have about colors in various ways, and extracting the latent variables from the data. Thus colors will be represented by high-level statistical constructs whose building blocks include the statistical correlations between various kinds of environments and the color experiences of various species. The resulting theory of color trivially satisfies (D1) – (D3), since colors would be individuated precisely as color science tells us they should be, with precisely as much vagueness as color science tells us they have. (Although we will not argue for it here, we suspect that many high-level properties of the special sciences are thought of this way by researchers in the field.)

Importantly, we regard the above theory of color as 'scientific' rather than 'philosophical' because the theory is not designed to give the metaphysical essence of colors, or to provide a conceptual analysis of color, or to accomplish many of the other tasks that have been assigned to traditional philosophical theories of color. Rather than telling us what colors are, the theory expresses what science tells us about colors. As we've seen, color science shows that colors are not easily captured in other terms – they are multiply realizable both microphysically and in terms of their spectral reflectance properties, etc. So at present we are not entitled to identify colors with some particular physical property, or any other relatively basic type of property. The best we can do is associate colors with a certain set of statistical regularities. This is not to say that colors are to be identified with some complex organization of statistical regularities, only that at present this is all we are entitled to infer about them. Whatever else colors are, they are the factors that can be extracted from certain types of statistical regularities. In that sense, the present theory is highly provisional. With each advance made by color science, there is a change in what the theory tells us about color. Moreover, the theory is consistent with many philosophical theories about what colors really are. Metaphysically speaking, colors could be physical properties, dispositions, or mind-dependent constructs of some sort. This outcome is standard for special science notions. Echolocators and head-initial languages are scientifically legitimate categories because of the work they do, and that is largely all there is to be said about them, ontologically speaking. Barring evidence of a radically different sort, there may not be all that much more to say about colors, either, ontologically speaking. In this sense, the major difference between colors and echolocators may be only that there have been fewer reductionist, dispositionalist, and anti-realist theories of echolocators than of colors.[13]

The main points made in this section might be summed up as a recommendation to let the epistemology of science and scientific inference guide one's metaphysical theories. While we are sympathetic to such a view, in this paper we have only defended the following weaker position: to the extent that a theory of color is motivated by a desire to articulate a theory or concept of color that is useful for scientific inquiry, the theory needn't treat colors as anything more than what is represented by the latent variables of the statistical analyses of the relevant data. Such a view incorporates precisely the information about colors that our best scientific theories provide us with. Thus, the resulting theory of color prevents no scientific inferences that our best theories legitimize, nor does it allow any inferences not supported by these theories. Any further detail added to a theory of color (e.g., that color must be or cannot be reducible to a single physical property, that they must be or cannot be a dispositional property, etc.) crucially involves extrascientific speculation. We do not rule out the possibility of important projects being motivated by such extrascientific speculation (e.g., Crook and Gillett 2001). However, we do stress that any such projects stand in need of motivation. That is, such projects cannot be defended as worthwhile on the grounds that they are helping to form a conceptual foundation for scientific activity. Those foundations, we claim, are laid in the details of statistical analysis.

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[13] It is interesting to contrast the provisional proposal on offer here with Hardin's anti-realist argument based on his claim that the parts of physical theory that treat the interactions of light and matter are currently well understood and are unlikely to be undermined by any future scientific revolution(s) (Hardin 1988, pp.59-60). We urge caution at drawing such a strong conclusion about what a future physics might say about the nature of color, as the track record of progress in physics and our current state of scientific knowledge would seem to leave plenty of room for surprises to turn up in physics. Thus we take the provisional nature of our theory to be a desirable characteristic.

5. Comparison with other views

The account of color proposed in this paper might be thought to have some affinities with 'functionalist' views of color. Over the years, a number of such views have appeared in the literature; e.g., Jackson and Pargetter 1987, McLaughlin 2002, and Cohen 2003. We take the reality of color to be a consequence of the indispensable role of colors in some of our best scientific theories and we have likened colors to the functional concepts of various special sciences. Unlike these other accounts, however, we are not offering a metaphysics of color. As was noted at the close of the previous section, our theory has very slim metaphysical commitments. The main virtue of the theory is that it offers a robust epistemology of color: we have focused on the roles colors play in our best scientific theories and how these roles support an account of what the sciences need from a theory of color. Attention to these details leads us to a rather impoverished account of the metaphysical underpinnings of scientific inquiry into color and related phenomena.

For an example of the kind of advantages our approach has over traditional functionalist accounts of color, consider the problem of properly individuating the colors in the light of the well-recognized phenomenon of significant variations in color perception, both inter- and intra-personal. The same object can look to be differently colored to different subjects in the same viewing conditions and to the same subject in different viewing conditions. The same object can also have a different chromatic appearance to the same subject in the same viewing conditions at different points in the life history of the subject. This sort of variation is an acute problem for functionalists who claim that e.g. "*red* is the property that disposes its bearers to look red" (Cohen 2003, p. 6). What are we to make of cases in which an object O looks red to a subject S_1 but O does not look red to a subject S_2? Is O red or is it not? On what principled basis would we make a decision? One might try to avoid this problem by treating colors as relational properties that are relativized to perceivers and contexts. But this does little to explain our everyday thoughts and utterances about color. As we noted earlier, folk intuitions about color suggest that most people take colors to be stable properties of objects. Furthermore, they don't normally talk of them being relativized to particular perceivers in particular circumstances. When Earl says, "The tomato is red," the most straightforward way of understanding his utterance is as making a claim about the tomato, not a claim about the tomato, himself, and the viewing conditions. Consider Cohen's (2001) reply to the above problem:

> ordinary color discourse depends tacitly on conventionally presupposed ways of filling out the relativizations …the predicate 'red' in our mouths denotes the property that disposes its bearers to look red to visual systems similar to our own and in circumstances like those we typically encounter. (Cohen 2002, pp.6-7)

We find this proposal to be inadequate on at least two counts. First, it makes an extremely strong assumption about the presuppositions in play in everyday discourse and thought about color. Cohen offers no empirical evidence to support this claim, and we know of none either. Thus, it's hard to see whether such a view is right or wrong. For example, careful study of the tacit parameters guiding everyday color thought and talk may reveal that people are absolutists about color rather than relativizers to a particular group and a particular set of circumstances. That is, people may normally take red to be a property objects have completely independently of how things seem to perceivers in color experience. It may also turn out that there really aren't any relevant tacit presuppositions that systematically guide color attributions. Clearly there are a number of other competing options that must be ruled out to establish Cohen's sort of relativized view of color.

It's also worth noting that in the passage quoted above, the individuation of color properties is given partly in terms of the pragmatics of speakers' language. It's unclear to us why we should suppose that a metaphysical view about color should be revealed by the pragmatics of human linguistic and cognitive behavior. The problem of properly individuating the colors with respect to scientific practice is a crucial one for any theory of color and Cohen's response to perceptual variation does not address the problem at that level. As he says:

> These presuppositions, which I claim tacitly attend ordinary ascriptions of color properties … will serve ordinary needs, despite being arbitrary (viz., stipulative, conventional). On the other hand, if objective color properties are needed for more recondite scientific or philosophical purposes, we may revert to the (wholly objective) relativized color properties (e.g., *red for S in C)*. (Cohen 2003, p.8)

Essentially, Cohen's position is that the tacit presuppositions play a role only in our everyday talk and thought about color, whereas they do not affect our metaphysical or scientific accounts of color. So, Cohen (rightly) is not actually using the presuppositions to do the heavy-duty work of properly individuating the colors. Rather, the presuppositions give us a means of accommodating within his theory the superficially non-relativistic color attributions made in everyday circumstances. That may be fine as far as it goes (depending on whether our first objection can be met), but it does nothing to address the more pressing issue. Scientific or metaphysical theories of color are still left with a swarm of color properties that are relativized to particular perceivers in particular circumstances. Such highly relativized properties are poor candidates for figuring in the explanations and generalizations of the sciences; it's one thing for color properties to be open-endedly multiply realizable and it's altogether something else for there to be an open-ended number of color properties. Thus Cohen's account fails to deliver a theory of color that is useful for scientific purposes, which violates our (D1).

In contrast, our view individuates the colors precisely in accordance with the latent variables extracted from the scientific data on color. This includes the degree of vagueness science tells us is present in the colors. Thus we are able to satisfy our own desiderata. Normal cases of perceptual variation pose no deep problem for our account, as the "hard cases" of variation will be absorbed by the degree of vagueness inherent in the scientifically appropriate individuation of the colors. There is no need for us to make unprincipled hard choices in such cases. Allowing the latent variables extracted from the scientific data to drive the individuation of the colors gives us a proper standard against which we can judge whether or not a particular color attribution is correct (e.g., in terms of outliers) and it enables us to accommodate cases in which subjects disagree about their color attributions.

6. Conclusion

In sum, the theory of colors as high-level statistical constructs is not a dispositionalist, reductionist, or anti-realist theory of any sort. The theory is silent about whether colors are any of these things. Color properties exist because they are part of our best scientific theories. However, it does not follow from this that colors are mind-independent properties of the world. We know that various sorts of color experiences interact causally with the world in various ways. It may be that this appeal to color experiences is an essential part of any successful characterization of colors, but then again it may not. (Notice that when constructing a theory, colors depend evidentially on color experiences; a separate argument is needed to show that color experiences causally depend on colors in some favored way.) Furthermore, the theory's current silence about whether colors are physical properties, dispositions, or properties of perceivers is, we think, an advantage of the theory. Such claims are largely empirical ones, and should be settled by methods other than those of philosophical analysis. Thus, our disagreement with the various traditional philosophical approaches to color is more methodological than substantive. Although our theory leaves many traditional philosophical issues unanswered, it is enough of a theory to understand how science proceeds and uses colors and color experiences. And if the theory is good enough for science, then perhaps it should be good enough for philosophy, too.

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