I am fascinated by the phenomenon of color, and, more specifically, how individuals perceive it differently. For the colorblind, color is merely various shades of grey with designated titles. To Synesthetes, color manifests as an association with words, letters, and sounds.

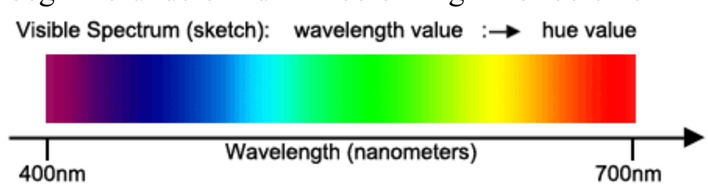
This research led me to three-dimensional zoetropes, which animate stationary objects as you watch. This concept - what you think you see is not truly what you will see - fascinated me. The PVC pipes easily flow together, with only their interiors painted to represent how they may look different depending on what you choose to focus on, or what angle you are standing at. The figures sit on a wooden board moved by a turntable, proving the relativity of not only perception vs. reality, but of my perception vs. yours. We often rely too heavily on our observations, which are not fact. The zoetrope suggests that we may need to change the homogenous way we think about color. Increasingly, I found that color was less of a fact and more of an experience.

Alexandra L.

When we look at a rainbow, do we all see the same colors? No, because when humans look at it we see Red, Orange, Yellow, Green, Blue, Indigo, Violet. But when colorblind people look at the rainbow, they see varying shades of gray that they've learned to assign ROYGBIV to. When a dog looks at a rainbow they only see green and blue. And when a mantis shrimp looks at it, they can see colors we don't even have names for. This concept that we don't see the "same" colors proves that my blue might be a pale variant of your blue, or might not even be blue at all but actually red, but I've learned that everyone else calls it "blue". This "color problem" is something scientists and philosophers have struggled to understand and prove for years. Although it is complicated for us to explain what we see because of the explanatory gap[1], we do have scientific evidence to prove that all people most definitely do not all see the same colors, or colors in the same way. Israel Abramov, a psychologist and neuroscientist, gave a group of men and women several different visual tests. Throughout his testing he found that women were able to tell the subtle differences between color when men could not[2]. So this brought to me the question: is perceiving color genetic? Associative? Psychological? Biological? And are we really seeing colors in the world as they truly are? From that, how can we go forward, how can we explain color and how do I know that my blue isn't your red? How do we interpret color and understand it in connection to the rest of our lives?

How We See Color

I began my research by posing the question: How do we see color? The answer was pretty straight-forward: when light hits an object that object absorbs certain light and reflects the light that it doesn't absorb[3]. This is known as the Albedo effect[4]. The wavelengths of light that are reflected/absorbed depend on the properties of the object. For instance, a banana has wavelengths that are around 570-580 nanometers, which means that the light that will bounce back is yellow. We are able to see these wavelengths because the light hits the back of our eye where the retina is located[5]. We first discovered the retina and its color-seeing abilities when Isaac Newton stuck a needle in the back of his eye, yes he really did, and saw prisms form, which was the first time that scientists began to understand that color might not be external but also internal[6]. Within the retina are photoreceptors called cones and rods; there are typically 6-7 million located in the retina. In the human eye 64% of cones respond to red light, 34% respond to green light,



[1] The explanatory gap is is a term introduced by philosopher Joseph Levine for the difficulty that physicalist theories of mind have in explaining how physical properties give rise to the way things feel when they are experienced.

[2] Copeland, Libby. "Where Men See White, Women See Ecru." *Smithsonian*. Smithsonian Magazine, Mar. 2013. Web. 14 Apr. 2016.

[3] Cousins, Carrie. "The Science Behind Color and Emotion." *The Science Behind Color and Emotion*. Design Shack, 30 June 2014. Web. 14 Apr. 2016.

[4] Davidoff, Jules. "Colors." Interview. Audio blog post. *Radiolab.org*. Radio Lab, 22 May 2012. Web. 13 Apr. 2016.

[5] Ibid.

[6] Newton was inspired by the German poet Johann Wolfgang Von Goethe and his poetry on the fireworks inside your eye when you close them

and only 2 % respond to blue light[7].

The human eye only has 3 different color receptors, which means we cannot see above 700nm, which is infrared or below 400nm, which is ultraviolet[8]. Other animals such as dogs have an even more regressed color palette, they can only see blues and greens. Whereas sparrows can see ultraviolet light, and butterflies have 5 color receptors so they have a much more advanced color palette than we do[9]. But surprisingly Mantis Shrimp have the most nuanced vision and can see colors that we can't even imagine. Perhaps they wouldn't understand what we mean when we combine all shades of a color and call it simply "blue" or "orange"; it would be as if a being with minimal ability to distinguish color had one word for all the colors in a rainbow[10]. This is similar to the Namibian tribe of Africa, who can't distinguish the difference between green and blue, but they can differentiate between shades of green that look identical to westerners[11]. So we can already see that there is a difference between colors existing externally and how sentient beings perceive or "see" them.

In addition, the way we perceive color is not explained solely by science and physical properties. There are many connections between our senses, especially vision, taste, and emotion. We live our lives surrounded by color, and often they provide boundaries and associations for us. Neuroscientist Jerald Kralik, who published a study on how rhesus monkeys perceive color, said, "Colors provide cues for everything from what is ok to eat to determining how others feel in different situations.[12]" The "Theory of Colours" by Johann Wolfgang Von Goethe shares a similar view on how color determines a large portion of our lives[13]. We associate color with more than simply hue; we associate color with deep emotional value. Because of that, advertisers have learned to manipulate us through color usage in ad campaigns. For instance, the color blue in a logo is interpreted as confidence, success, and reliability. The color purple represents femininity, glamour and charm; and green logos represent eco-friendliness, toughness, durability, sustainability, and masculinity[14]. Though we make these unconscious associations between color and emotion, most of us have separate senses, and we don't associate our other senses together. However, people who have a condition called *Synesthesia* do.

Hearing, Tasting, and Feeling Color

Synesthesia is simply crossed senses[15]. The scientific definition of Synesthesia is "[an] irregular sprouting of new neural connections within the brain which leads to a breakdown of the

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7 Harrington, Rebecca. "Use This Cool Phone Trick to 'see' a Color of Light Human Eyes Can't Detect." *Tech Insider*. Tech Insider, 21 Sept. 2015. Web. 13 Apr. 2016.

8 Ibid.

9 Davidoff, Jules. "Colors." Interview. Audio blog post. *Radiolab.org*. Radio Lab, 22 May 2012. Web. 13 Apr. 2016.

10 Ibid.

11 Do You See What I See?" *WatchDocumentary.com*. BBC, Horizon, 17 Aug. 2011. Web. 14 Apr. 2016.

12 Cousins, Carrie. "The Science Behind Color and Emotion." *The Science Behind Color and Emotion*. Design Shack, 30 June 2014. Web. 14 Apr. 2016.

13 Ibid.

14 Vsauce. "What Color Is A Mirror?" *YouTube*. YouTube, 03 Aug. 2012. Web. 14 Apr. 2016.

15 "Synesthesia: Tasting Words, Seeing Sounds, Hearing Colours And More." *PsyBlog RSS*. PsyBlog, 01 May 2014. Web. 14 Apr. 2016.

boundaries that normally exist between senses[16].” Someone with synesthesia can physically feel, taste, and hear colors. “Chocolate is rich purple and makes my breath smell dark” says one synesthete[17]. This might sound ridiculous, or certainly incomprehensible, to most of us, but in recent years scientists have grudgingly accepted it as a true condition, due to its neurological basis. It is uncommon in adults but scientists believe that when we are infants we are all synesthetes. Research shows that infants, unlike adults, have one all-encompassing sense instead of five[18].

In a recent study it became apparent that synesthesia might not be innate. Psychologists at the University of Amsterdam published a study on Colorgraphemic Synesthesia, which is a condition where people perceive colors when reading letters[19]. To test this, they gave a hundred people text that had been customized so that each word was a different color. This was meant to test people’s color-letter associations, and they found that the associations were able to exist independent of the letters themselves[20]. Although we can’t necessarily teach ourselves Synesthesia, we can achieve “pseudo-synesthesia” by taking two categories such as color and letters and create associations between the two and repeatedly practice until it becomes natural[21].

There isn’t just one type of synesthesia, there are actually several. They all fall between the two categories of *projective* and *associative*[22]. Projective is when an image or color is projected out in front of you in the visual field, and associative is when an image or color appears in your mind. One woman, Brit Brogaard, experiences an unusual manifestation of Synesthesia. Hers is fear-induced; she sees an eerie blue and green “spiky” landscape about 30cm in front of her eyes when she experiences fear[23]. In this case this phenomenon actually protected her once from almost stepping on a rattlesnake. Synesthesia can lead to some extreme cognitive abilities. For instance, Daniel Tammet, a synesthete, can recite the first 22,514 digits of *pi* from memory, based on his strong color-number associations[24]. Synesthesia is the capability of associating two

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[16] Ibid.

[17] Than, Ker. "Rare but Real: People Who Feel, Taste and Hear Color." *LiveScience*. TechMedia Network, 22 Feb. 2005. Web. 14 Apr. 2016.

[18] Ibid.

[19] Garber, Megan. "Can You Teach Yourself Synesthesia?" *The Atlantic*. Atlantic Media Company, 6 July 2012. Web. 14 Apr. 2016.

[20] Ibid.

[21] Gregoire, Carolyn. "Yes, You Can Teach Yourself Synesthesia (And Here’s Why You Should)." *Huffingtonpost.com*. Huffington Post, 8 Sept. 2015. Web. 13 Apr. 2016.

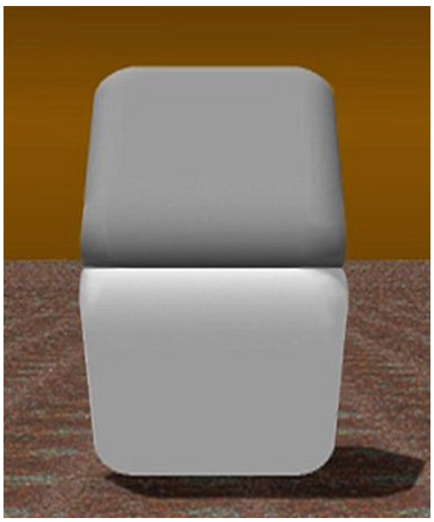
[22] "Types of Synesthesia." *Synesthesia Test*. The Synesthesia Community, 24 Apr. 2009. Web. 14 Apr. 2016.

[23] Gregoire, Carolyn. "Yes, You Can Teach Yourself Synesthesia (And Here’s Why You Should)." *Huffingtonpost.com*. Huffington Post, 8 Sept. 2015. Web. 13 Apr. 2016.

[24] Ibid.

unconnected senses into a single category, which is why it is possible to learn. The connection between the senses only exists for a few; the rest of us experience color in a way that what you see is only what you see.

Unlike taste and touch, the color spectrum only exists on a singular line. Thus it should be relatively easy to measure or describe something using color. Yet in the case of color it becomes more of a mystery because the area is so vast and expansive, and all we have is a line to measure it, with segments that the naked eye can't even see. One interesting aspect of color is the fact that it hovers between the subjective world of sensation and the objective world of fact. The many optical illusions that have been created prove this, for instance when you look at the box, you can clearly see two distinct colors: light gray and dark gray.



But when you cover the line between the two squares, they appear the same color. Optical illusions blur the line between sensing and fact, between internal perceptions and external realities.

Perception Vs. Misconception

The way we differentiate these two worlds varies. Scholastic Realism[25] suggests that objects have only those colors that observers perceive. When one seals a stamp with hot wax they leave an imprint in it, which is what happens to our eyes with color. In this case, color is leaving an imprint on our eyes temporarily. Since this idea of scholastic realism presents no conflict between what we individually see and what's actually there, it was a fairly convincing model; proving what people wanted to believe: that color is what it looks like[26]. In the 17th century, Galileo[27] suspected the opposite of what people thought they understood about color. "[Color] holds their residence solely in the sensitive body; so that if the animal were removed, every such quality would be abolished and annihilated[28]." This provokes the question of whether color is internal to the observer or external in the thing itself. Which brings us back to the question of how we measure color, because we are incapable of defining colors the way we can with other physical qualities. So is it all in our heads? We rely too heavily on our personal experiences and observations to guide our scientific experiments, especially in the concept of colors. For us to believe in the atom, we have to accept that our perceptive faculties have extremely limited access to the physical world. "How weird it is to even expect there to be a connection between the manifest visual world, brought to us by our senses, and the rarified scientific image of a world made up of physical particles[29]." Says M. Chirimuuta, author of the book Outside Colors. So we have myriad examples of accepting things that we believe are true but for which we personally have no data or sensory proof.

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[25] Also known as Aristotelian Realism

[26] Chirimuuta, Mazvitta. "The Reality of Color Is Perception - Issue 26: Color - Nautilus." *Nautilus*. N.p., 23 July 2015. Web. 02 May 2016.

[27] Sometimes known as the "philosopher of inversions"

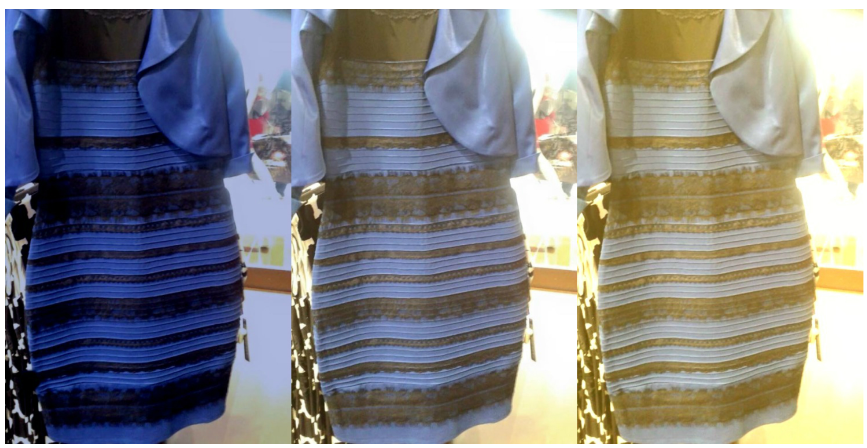
[28] Galileo's Il Saggiatore

[29] Chirimuuta, Mazvitta. "The Reality of Color Is Perception - Issue 26: Color - Nautilus." *Nautilus*. N.p., 23 July 2015. Web. 02 May 2016.

We assume that our perception is true and consistent; in fact, we unconsciously depend on that consistency in almost everything we do. In reality, though, it was once far opposite from that. When Galileo showed that color was in the brain, scientists were left with the question of where in the brain. Modern biologists developed different models to prove this theory. *Trichromacy* derives its name from the three different cones that exist in our eyes, which create the cardinal colors red, blue and yellow[30]. These three colors then create all the other colors that we see in the color spectrum. The *Opponent Process Theory* states that the information from cones travels down two cardinal channels being red-green and blue-yellow, as well as another for brightness[31]. Together these create the color spectrum through contrast. If we assume this theory to be correct, we can conclude that lighting conditions interact with the eye and process the information, which results in wavelengths representing colors[32].

The Illusion of Color

The idea that lighting conditions influence our color perception is a very common misconception for it can be extremely misleading. One example that took social media by storm last February is "The Dress." (The blue-black version or the white-gold version). Thousands of people stared at this dress and could not come to one consensus. The reason for that is due to Qualia. "Qualia" means that what something looks like is separate from the question of what it is[33]. Philosopher Thomas Nagel addressed this concept in his essay "What Is It Like To Be A Bat." He proclaimed, "We describe bat sonar as a form of three-dimensional forward perception; we believe that bats feel some version of pain, fear, hunger, lust and that they have other, more familiar types of perception besides sonar." This applies to the concept of the color of "the dress" because I personally can't see the black and blue dress, but can imagine what it would look like. But I will never be able to understand the experience of seeing that dress as black and blue.



Nagel goes on to say, "But we believe that these experiences also have in each case a specific subjective character, which it is beyond our ability to conceive." I took a poll of the four students who were sitting around me and asked how they perceived the dress. I assumed that we all would see it the same way; as artists we pride ourselves on our relationships to color. But shockingly I was the only one who saw the dress as white and gold, everyone else saw black and blue! My instinctive reaction was that they were wrong and I was correct because this was the way I saw it. But am *I* seeing it correctly? Maybe in actuality the dress is black and blue, and I'm the one seeing it

30 Do You See What I See?" *WatchDocumentary.com*. BBC, Horizon, 17 Aug. 2011. Web. 14 Apr. 2016.

31 Ibid.

32 Ibid.

33 Yglesias, Matthew. "What That Weird Dress Tells Us about the Metaphysics of Consciousness." *Vox*. N.p., 26 Feb. 2015. Web. 02 May 2016.

wrong, even though I could swear that I'm correct. And in fact to me and to how my eyes perceived it, I am correct. This dress demonstrated the idea that color is not a fixed external object of sight, but it's a *way* of seeing things. The dress is neither, but it forced us to investigate our environment: several people tilted their screens to adjust the light, in order to see it the opposite way and succeeded[34]. Humans are innately curious, and this was a perfect example of "philosophical investigation[35]"of the highest and most human order.

We Can Never Really Know Others' Senses

This limiting nature of how we perceive the dress illustrates the idea that we can't know others, we can only observe them. None of our observations will give us direct access to others' actual thoughts, feelings, or experiences. We can prove that we all interpret color differently, but we will never be able to validate what we all see. We can't experience how someone else thinks, tastes, or feels, so how can we assume to see like them too? For example, cilantro is a common herb that many people enjoy eating, but to some it tastes like soap. It's likely that our sight experience is similar, but we can't truly explain that either. We assume that "flavor and color experiences are uniformly correlated with certain physical stimulations of the sense organs.[36]" But we have no evidence for that claim of uniformity, only assumptions. All we can do is observe the correlations between our experiences and others' experiences. But if all of our ideas come from instinct and assumption, is it really knowable? It's all just belief like so many aspects of our physical world. Because what can we really know about the conscious life in this world beyond the fact that we individually have a conscious mind[37]?

We could claim that perceived color is relative, whereas actual color is not objectively real. So are they both subjective? We could also reject the distinction between perceived color and actual color[38]. But why would we do this? It is a fact that we all see/perceive color differently, and there is one way we can begin to prove it. Assume a bowl of water is sixty-five degrees. If one person has been running their hand under ninety degree water for a minute, and a second person has been running their hand under thirty-five degree water, how will they perceive the water in the bowl when they stick their hand in it? Obviously differently, even though the water is at a fixed temperature[39]. Perhaps all perceptions are experienced similarly to the water.

We may even need to change the way we think about color. How can we begin to describe it without truly understanding how we comprehend it? There is one examination of our color knowledge called Color Adverbialism[40]. This is the concept that color should be treated adverbially, so for example one would see the sky bluely. For colors are not simply experiences, objects, or lights, but rather are "perceptual processes", an intersection between the three. Colors

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34 W, Justin. "The Dress: A Philosophy Problem Gone Viral (a Few Updates) - Daily Nous." *Daily Nous*. N.p., 27 Feb. 2015. Web. 02 May 2016.

35 Ibid.

36 Chirimuuta, Mazvitta. "The Reality of Color Is Perception - Issue 26: Color - Nautilus." *Nautilus*. N.p., 23 July 2015. Web. 02 May 2016.

37 How do we know that rocks aren't conscious? Descartes

38 "What If Two People Call a Color the Same Name but Their Eyes See Different Colors? Is It Proven That That's Not Possible?" *UCSB Science Line*. UCSB Science Line, 28 Feb. 2013. Web. 13 Apr. 2016.

39 Ibid.

40 Chirimuuta, Mazvitta. "The Reality of Color Is Perception - Issue 26: Color - Nautilus." *Nautilus*. N.p., 23 July 2015. Web. 02 May 2016.

are properties of processes in this theory, thus they should not be treated as adjectives which describe things[41]. But rather as adverbs which describe activities.

It’s clear that we all interpret colors differently. We now know that color is not only external but internal, which ensures that we all have a different color experience. Though we have all been taught to call a certain color red, that color is different for men, women, colorblind people, dogs, butterflies, mantis shrimp etc. In fact there are even correlations between colors and other senses. Those who are considered synesthetes have a stronger connection between color and all the senses, which is something most of us don’t have. But we can blur the line between sensation and fact by looking at optical illusions, such as the dress (which confused and irritated millions and generated extreme visceral responses). This serves to prove the relativity of not only perception vs reality, but of my perception vs yours. And sometimes what we think we see is not even there! We often rely to heavily on our observations, which are not fact. We can never know others we can only observe them. And our observations will never give us direct access to others’ actual thoughts, feelings, or experiences. We may even need to change the way we think about color. For color is really an experience, not a fact.

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[41] Ibid.

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