Studies in History and Philosophy of Science 47 (2014) 26–41

Contents lists available at ScienceDirect

Studies in History and Philosophy of Science

journal homepage: www.elsevier.com/ locate/shpsa

The Munsell Color System: A scientific compromise from the world of art

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A R T I C L E I N F O

Article history:
Received 14 April 2013
Received in revised form
16 March 2014
Available online 11 June 2014

Keywords:
Color systems;
Color perception;
Color science;
Albert Henry Munsell;
Munsell Color System

A B S T R A C T

Color systems make accurate color specification and matching possible in science, art, and industry by defining a coordinate system for all possible color perceptions. The Munsell Color System, developed by the artist Albert Henry Munsell in the early twentieth century, has influenced color science to this day. I trace the development of the Munsell Color System from its origins in the art world to its acceptance in the scientific community.

Munsell's system was the first to accurately and quantitatively describe the psychological experience of color. By considering the problems that color posed for Munsell's art community and examining his diaries and published material, I conclude that Munsell arrived at his results by remaining agnostic as to the scientific definition of color, while retaining faith that color perceptions could be objectively quantified. I argue that Munsell was able to interest the scientific community in his work because color had become a controversial topic between physicists and psychologists. Parts of Munsell's system appealed to each field, making it a workable compromise. For contrast, I suggest that three contemporary scientists with whom Munsell had contact – Wilhelm Ostwald, Ogden Rood, and Edward Titchener – did not reach the same conclusions in their color systems because they started from scientific assumptions about the nature of color.

1. Introduction: the Munsell Color System

Color systems provide a way to effectively communicate about color by graphically organizing all possible color percepts and notating the relationships of those colors in a quantitative way. This organization makes accurate specification and matching of colors possible in science, art, and industry. Working in the first decades of the twentieth century, the American painter Albert Henry Munsell developed the first successful and widely accepted color system. His system is today an internationally recognized standard, is used by the American National Standards Institute and the USDA, among others,[1] and provided the theoretical basis for many modern-day color systems.

Some examples of uses for the Munsell System are in design and fashion industries, which must match the colors of paint, ink, and dyed fabric; environmental and archaeological description of soil color; forensic pathologists' identification of hair, skin, and eye color[2]; and food products standardized and graded by color.[3,4] The Munsell System's concepts have been pervasive: Edward Landa and Mark Fairchild write that Munsell's work "…has had an impact on essentially all modern systems of color measurement and

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[1] Munsell Color, "Color Standards," http://munsell.com/color-products/color-standards/.

[2] Landa and Fairchild (2005), p. 440, for an interesting discussion of some applications of Munsell colors.

[3] McLeary (in Goodyear and Weitekamp (2013)), provides an excellent discussion of the work the Munsell Color Company did with various industries to make the Munsell System a profitable and influential part of science and industry, pp. 47–49.

[4] See Nickerson (1977a [1969]), p. 127, for some of the historical uses of Munsell color scales (including measuring the color of chocolate cakes for USDA), and see http://munsell.com for examples of color-grading products offered today.

http://dx.doi.org/10.1016/j.shpsa.2014.03.004

specification." They contend, "No other color system from this time period has been as long-lived, commercially successful or influential."[5]

Munsell was trained and practiced as a painter, and his system was used in art manuals,[6] elementary school education,[7] and continues to be used by some practicing artists today.[8] However, Munsell consulted with several eminent scientists in the United States while developing his system, and his system was ultimately adopted primarily for scientific purposes.

This paper addresses the success of the Munsell Color System by tracing its source from the needs and knowledge of the art world, describing the peculiar features of the system that emerged from this origin, and demonstrating how those features made it uniquely suited to contribute to the scientific investigation of color.

1.1. The Munsell Color System and its unique features

The Munsell Color System consists of two parts[9]: the color charts or "atlases," which are purchasable samples of color, and the theoretical system, which describes the human experience of color, also called the perceptual "color space." In 1905, Munsell explained the theoretical structure in *A Color Notation*, and in 1915 he published the first colored paper samples in the *Atlas of the Munsell Color System*. Though the samples have changed over time with further research and refinement,[10] the theoretical structure of the system has remained the same.

Color systems and color atlases existed before Munsell's work. Rolf G. Kuehni and Andreas Schwarz in their comprehensive book, *Color Ordered: A Survey of Color Order Systems from Antiquity to the Present* (2008), describe the history of how the complex idea of "color" has been visualized in graphical, diagrammatic ways. They write that color systems developed from one-dimensional to two-dimensional and then three-dimensional representations, and give as paradigmatic examples of each the "strictly lightness-oriented scale of Girolamo Cardano (1550), Newton's chromatic color plane of 1704, and Range's 1810 color sphere."[11]

Munsell was familiar with previous attempts to diagram color and to create complete samples of color standards. In the opening pages of his diaries, which he kept from the late 1880s until his death in 1918, he noted reading Ogden Rood's *Modern Chromatics* (1879) in 1879 and Michel Eugène Chevreul's *Principles of Harmony and Contrast of Colors* (1855) in 1887.[12] Both of these works attempt to schematically organize all colors in geometric diagrams (an inverted cone in Rood's case and a hemisphere in Chevreul's). The diaries also contain two pages of notes from Milton Bradley's book *Elementary Color* (1895), which was one of the first attempts to provide a small set of "color standards" as squares of colored paper organized in rows of hues and columns of tints and shades.[13]

However, Munsell's system was marked by subtle modifications on the historical precedents for organizing color. A detailed description and comparison of all preceding color systems with Munsell's will not be possible in this space, though the reader may notice similarities between the Munsell System and other color systems. The following discussion will outline the basic structure of the Munsell System and point out the unique features of the Munsell System that will be important for the argument of this paper.

In the Munsell System every possible color percept can be described by three variables: hue (the color name: red, blue, green, etc.), value (lightness or darkness), and chroma (purity, or difference from neutral gray). Every color is alpha-numerically labeled with a letter for the hue, a number for the value, and a number for the chroma. If two Munsell Color samples are equal on one variable; they will appear the same in that attribute even if the other two variables are different. The independence of these variables was a novel feature of the Munsell System.

With this structure Munsell experimentally changed one variable of color at a time to produce scales of samples that appear to change at a perceptually uniform rate. This was a novel and unique feature,[14] and one that his fellow artist Denman Ross described as "equal intervals of equal contrasts in all directions."[15] Munsell organized all the color samples into a three-dimensional solid shape with hue, value, and chroma as the three axes. Munsell was the first to create an irregularly shaped color solid, as he found through experimentation that certain hues reach their strongest chromas at different value levels[16] and some hues are capable of attaining greater maximum chromas than others.[17] This was opposed to the smooth-contoured, geometrically-inspired spheres, cones, and triangles common to other color systems of the time (see Figs. 1 and 2 for a comparison of the Munsell color solid and other color solids).[18] Munsell thereby discovered and accurately mapped the peculiarities of human color perception (see Figs. 3 and 4 for a conceptual diagram of the Munsell System and a representation of the irregular color solid).

In his experimentation Munsell relied on contemporary scientific tools, but used them in ways tempered by his judgment. To establish a value scale, he invented a new type of photometer with a "cat's-eye" shutter to scale the measurement of reflected light to the Weber–Fechner law of sensations, which states that the stimulus must be increased geometrically for the sensation to increase arithmetically.[19] This photometer allowed a value scale corresponding to our psychological experience of an equal

[5] Landa and Fairchild, (2005), pp. 436–437. Mark Fairchild is Associate Dean of Research and Graduate Education at the College of Science, and Professor of Color and Imaging Sciences at Rochester Institute of Technology. Edward R. Landa is a research hydrologist with the U.S. Geological Survey in Reston, Virginia.

[6] For example, Walter Sergeant's book *The Enjoyment and Use of Color*. Chicago: Charles Scribner's Sons (1923), cites Munsell on p. 7.

[7] The Munsell Color Company originally manufactured children's school art supplies as part of the business. Nickerson (1940), p. 580.

[8] I first encountered the Munsell system in art classes at the Grand Central Academy of Art in New York. http://www.grandcentralacademy.org/.

[9] Shevell (2003), p. 196, also sees the Munsell System as a theoretical part and a practical part.

[10] The color samples were first updated in the 1929 *Munsell Book of Color*. In 1943 they were measured spectrophotometrically and published as CIE tristimulus values, known as the Munsell renotations. ("CIE" stands for the French "Commission Internationale de l'Eclairage or International Commission on Color).

[11] Kuehni and Schwarz (2008), 21.

[12] Munsell diaries, p. 1. Citations from Munsell diaries throughout this paper come from the digitized PDFs of a typewritten transcription (created by his secretary in the years 1920–3) of the original handwritten documents. The PDFs are available at The Rochester Institute of Technology's Munsell Color Science Laboratory website: <http://www.cis.rit.edu/research/mcsl2/online/munselldiaries.php>.

[13] Bradley (1895), p. 41 for a diagram and explanation of the Bradley color standards.

[14] Kuehni and Schwarz (2008), p. 14.

[15] Munsell diaries, May 20, 1900, p. 33.

[16] For example, maximally saturated yellow appears lighter than maximally saturated purple. Crone (1999), p. 114. Also see Kaiser and Boynton (1996), p. 504, for a discussion of the relationship between lightness and hues.

[17] Long and Luke (2001), p. 7.

[18] Kuehni and Schwarz (2008), p. 115 also claims that Munsell advanced color theory by understanding that a perceptually uniform color solid could not be a simple geometric solid.

[19] Nickerson (1940), p. 576.

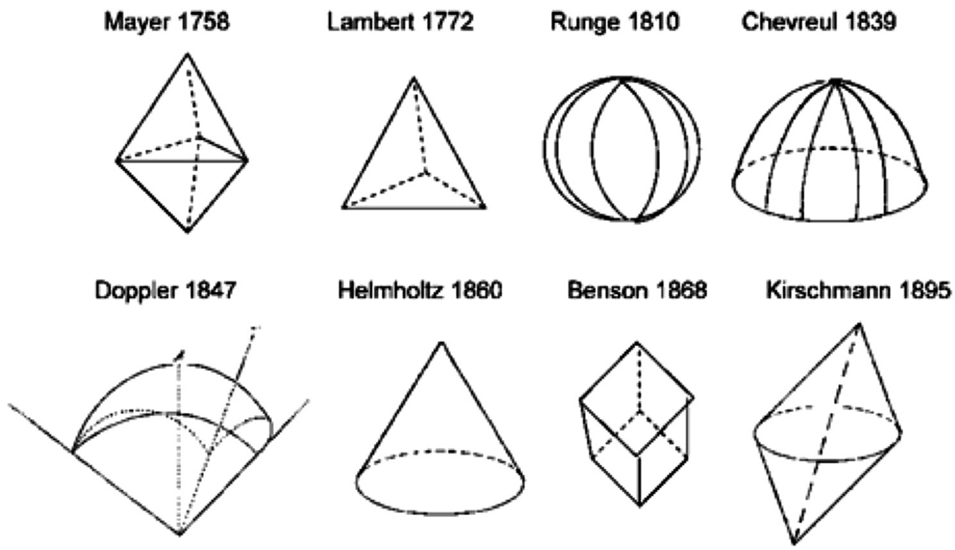

Fig. 1. Other color systems preceding Munsell's. Notice that all are idealized geometric shapes. Image from Kuehni (2002), p. 21. Copyright © 2002 John Wiley & Sons, Inc.

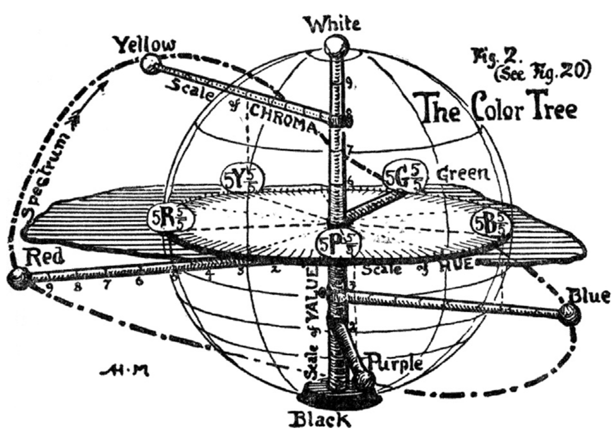

Fig. 2. The Color Tree. This schematic diagram of the Munsell color solid, which Munsell called a "color tree," shows how the solid follows a basic spherical plan. However, the actual contour of the solid, demonstrated by the dotted and hatched lines, is irregular as chroma extends out from the central axis to different lengths for each color. Image from Munsell (1907 [1905]), fig. 2, p. 23.

gradation to be read directly from the physical measurement of intensity.[20]

To establish his hue circle and chroma scales, Munsell used Maxwell disks, so-called because they were popularized by James Clerk Maxwell.[21] Pieces of colored paper are placed on a disk and spun rapidly, and the ratios of their areas on the disk are numerically recorded when they mix to match another color sample. Maxwell disks have benefits over working with spectral lights or physically mixing pigments. Since the colors are blended in the eye, this method avoids problems caused by chemical reactions and impurities or differences in strengths of the pigments. Since they use surface colors, rather than lights, the results are more appropriate for real-world color matching applications.

Munsell chose his primary hues arbitrarily so that they would "balance," or spin to appear neutral gray.[22] He was intrigued with the decimal system,[23] and so chose five primary hues and a zero-to-ten value scale such that all the samples can be divided into finer increments with decimals if necessary.[24] He created his chroma scales by spinning pairs of complimentary hues of the same value on a disk, recording the ratio of areas that spin to neutral gray, and then adding a proportional amount of gray to lower the chroma of the more chromatic sample. Samples were labeled with equal chroma numbers when they spun to gray with each occupying half the disk.[25]

Although Munsell used scientific tools and read the contemporary scientific literature about color, he refrained from defining his color samples by wavelength, pigments, or introspective analyses about color. Instead, he worked only within the definitions of his system itself. In his first steps he translated his photometric measurements or painted papers for Maxwell disks into Munsell notation, and only referred to them by the notation system from then on in his process.

1.2. *Outline of the historical argument*

I argue that Munsell's artistic training in the French Academic tradition during the burgeoning of Impressionism and Neo-Impressionism accounts for his motivation to solve particular problems of color. Moreover, his artistic training is likely to have provided the inspiration for many of the features of his system that make it unique among contemporary color systems and successful in a wide variety of fields and industries. I claim that Munsell's system was successful because he did not define color according to external variables, such as the physical properties of spectral light, but instead remained agnostic as to what, scientifically, color "is." The self-contained characteristic of his system allowed Munsell to be the first to accurately and precisely describe the psychological and phenomenological color space – our perception of color –

[20] Gibson and Nickerson (1940), p. 597.
[21] Turner (1994), p. 100.
[22] Nickerson (1940), p. 576.
[23] Kuehni (2002), p. 22.
[24] Nickerson (1940), p. 576.
[25] Munsell (1907 [1905]), pp. 68–70.

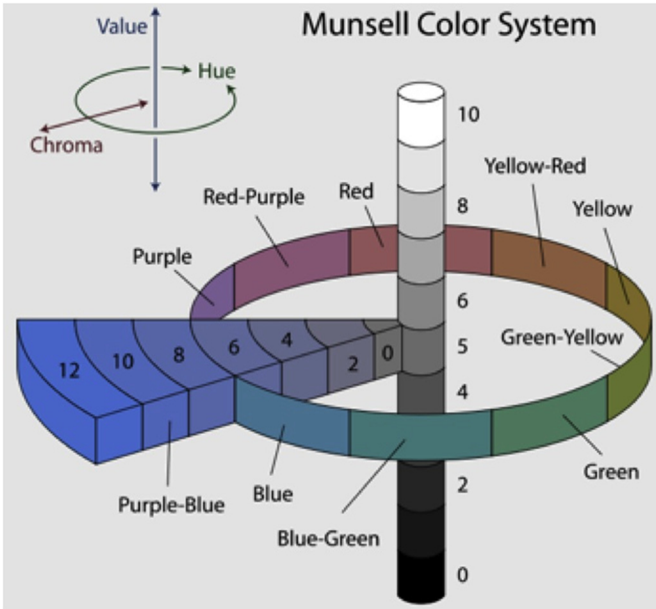

Fig. 3. Schematic diagram of the Munsell color system. Value is on the vertical axis, from black to white; the hues run in a circle around the vertical axis, and the chroma scale extends outward perpendicular to the value axis. Image by Jacob Rus, 2007.

rather than the physical or physiological correlates of color. His experimental methods and the resulting system's unique characteristics appealed to certain conventions followed by physicists and psychologists, making it a workable compromise in the scientific debate about color.

Munsell was able to straddle the boundary of the worlds of art and science. The diaries he kept from the late 1880s until his death in 1918 show that while he earned his living as an artist, he kept up to date with the latest research related to color in physics, physiology, and psychology. He met and corresponded with the leading scientists of his time. Yet Munsell's practical, working experience with color and his decision to *not* incorporate all of contemporary scientific research may have helped him to make one of the first and most accurate psychophysical color systems.

Research after Munsell's death in understanding how retinal photoreceptors function in response to the stimulus of light made it possible to standardize the external variables that influence our perception of color. Holding these variables constant now removes them from the problem of creating a psychologically accurate color system.[26] Such standardization does explicitly what Munsell was doing implicitly by ignoring the scientific questions of his day about the "source" of color.

[26] Many standards were adopted in the 1931 International Commission on Illumination (ICI or CIE for the French): they adopted standard illuminants and a standard observer based on tristimulus values which relate indirectly to the spectral sensitivities of the three cone cells (Yasuhisa Nakano in Kaiser and Boynton (1996), p. 544) and limited the field of view in order to avoid distortions caused by the unequal distribution of cones over the retina. In 1940 the OSA subcommittee on the spacing of Munsell Colors set a standard viewing light source and viewing angle, a length and mobility of fixation, and mounted the charts on neutral grounds with ICI tristimulus specifications. These standards accounted for intensity and wavelength reflectance, retinal adaptation, and controlled for psychological phenomena like contrast and end-effect (Newhall (1940), pp. 622–23).

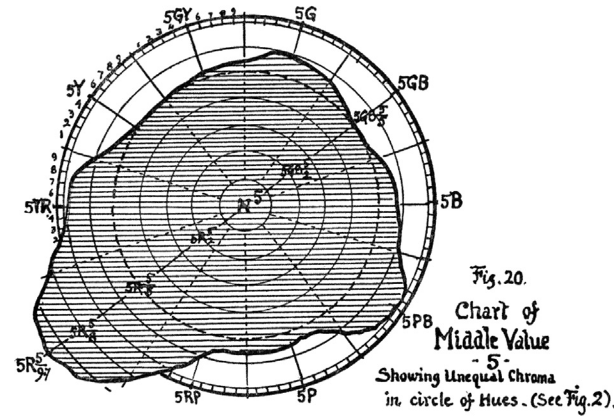

Fig. 4. A Chart of Middle Value 5, Showing Unequal Chroma. This cross-section shows the irregular contours of the color solid. Image from Munsell (1907 [1905]), fig. 20, p. 74.

2. The problems of color in the art world

The discourse about color in Munsell's art world sheds light on why he developed his system and the functions he designed it to fill. Munsell was born in 1858 and studied at the Massachusetts Normal Art School. After he graduated in 1881 he was hired as an instructor there. From 1885 to 1888 he traveled to Europe, where he first studied in Paris at the Académie Julian. The Académie Julian was a private atelier that employed some of the leading Academic artists of the day – William Bouguereau, Tony Robert-Fleury, Gustave Boulanger, Jean-Paul Laurens, and Jules Lefebvre, among others[27] – to teach and prepare the students for entrance examinations to the École des Beaux-Arts. It attracted an international body of students, especially from America, and was the first atelier to open its doors to women.[28] Munsell was accepted to the École, where he won second prize in his first yearly competition and later the Catherine de Medici scholarship, allowing him to study abroad in Rome for a second year. After his return to the United States he painted, primarily portraits and seascapes, and taught at the Massachusetts Normal Art School (now MassArt) until his death in 1918.[29]

Munsell's artistic education happened at a particular crossroads in art history, when the traditional, structured education of the École and associated private ateliers was still available, but the new nineteenth-century movements of Romanticism, Impressionism, and Neo-Impressionism had challenged the old order. Overlapping with Munsell's education, the first Impressionist Exhibition was held in 1874, and the Neo-Impressionists showed with the last Impressionist Exhibit of 1886.[30] These movements emphasized the problems of color that already existed in the Academic tradition, and tried to answer them in new ways. In the Academy, color had been considered the most difficult, if not impossible, aspect of art to teach – something that required an "eye," or innate talent. With the breakdown of the authority of the Academy,[31] the qualities of "genius" and "originality" that were associated with color became

[27] Weisberg and Becker (1999), p. 15.

[28] See Weisberg and Becker (1999) for a history of the women's ateliers in the Académie Julian.

[29] Nickerson (1940), p. 575.

[30] Ratliff (1992), p. 29.

[31] For a history of the Academy, the Institut, the École, and the definition of Academic style see Boime (1971), Chapter 1, "The Crystallization of French Official Art," pp. 1–15.

more highly prized, especially by the Romantics, who emphasized the importance of color to express the emotions of the individual.[32] Furthermore, the Impressionists' interest in plein air (outdoor) painting and the effects of sunlight added to the problems of reproducing color on canvas. The Neo-Impressionists attempted to answer these problems of color by studying the contemporary scientific discoveries related to the physics of light, physiological optics, and psychology of color.[33] Munsell's Academic training in this climate of artistic color problems helps explain his motivation to rationally systematize color to make it teachable.

The Impressionist revolution exacerbated two questions that had plagued artistic color: the first was how to correctly match colors seen in nature on the canvas, and the second was how to teach the aesthetics of compositional color harmony. Correctly matching the colors of nature had already been considered more difficult to teach and master than drawing. John Ruskin, the influential artist and art critic of the Victorian age, wrote in *Elements of Drawing* that while it was possible through work to become a reasonable draftsman, "…to color well, requires your life. It cannot be done cheaper."[34] Ruskin explained that coloring accurately was difficult because "while form is absolute, so that you can say at the moment you draw any line that it is either right or wrong, color is wholly *relative*. Every hue throughout your work is altered by every touch that you add in other places; so that what was warm a minute ago, becomes cold when you have put a hotter color in another place, and what was in harmony when you left it, becomes discordant as you set other colors beside it…"[35] Ruskin later implied that the ability to match color may be inborn, rather than acquirable, as he wrote of the need for an "eye for colour."[36]

Creating pleasing color compositions was considered even more indefinable and unteachable than correctly matching colors. Even though Ruskin's treatise was aimed at teaching the fundamentals of drawing to any eager student, he described the ability to harmonize color compositions as innate: "As to the choice and harmony of colors in general, if you cannot choose and harmonise them by instinct, you will never do it at all."[37] He seemed to divide the world into those blessed with a color sense and those without it when he said, "If color does not give you intense pleasure, let it alone; depend upon it, you are only tormenting the eyes and senses of people who feel color, whenever you touch it; and that is unkind and improper."[38] This is not peculiar to Ruskin. Ogden Rood, in *Modern Chromatics*, also wrote, "training or the observance of rules will not supply or conceal the absence of this capacity in any individual case."[39] According to Albert Boime, in the philosophy of the Academy "Drawing (dessin), considered the rational basis of the arts, was theoretically transmissible from teacher to pupil and, as such, its mastery was not considered a natural gift."[40] Good color (including compositions), however, "was not subject to rules and could not be taught; it was a natural gift, a characteristic of genius."[41]

Impressionist and plein air painting made the problem of matching colors more difficult because the effects of sunlight, as opposed to traditional indoor studio lights, are fleeting and create a range of values greater than pigments can imitate.[42] Furthermore, Impressionism cemented the notion that color composition was an innate and unteachable skill by emphasizing spontaneity and originality. As the authority of the more formal, traditional Academic practices broke down in the last decades of the nineteenth century, Boime wrote that the individual artist's "sincerity and individuality emerged"[43] as important features of a painting. Richard R. Brettell in his book, *Impression: Painting Quickly in France, 1860–1890* pointed out the connection between the two concerns: because the Impressionists were working with more speed to capture the flux of nature, their paintings were imbued with a certain spontaneity that was seen to reveal the highly individual nature of the artist.[44] In 1863 the École was reformed with an official imperial decree that, among other things, broadened the standards of judgment for competitions. These reforms reinforced the idea that originality was to be prized, and therefore undermined the need for or possibility of artistic instruction. Boime concluded: "The report intimated that if you were unique there was no necessity to compete, and finally, no need to go to school."[45] And Brettell wrote that a common criticism of Impressionism at the time was that it "question[ed] by its very nature certain traditionally accepted values of education, memorization, and collective knowledge."[46]

Artists did not abandon the quest to understand color, however. The Neo-Impressionists disliked the instinctive, spontaneous Impressionist method, and turned to color science for answers. Georges Seurat, like Munsell, first studied at a municipal art school drawing from plaster casts and copying lithographs before entering the École des Beaux-Arts in 1878.[47] Seurat, like Munsell, studied Chevreul's *Principles of Harmony and Contrast of Colors* (1855) and Rood's *Modern Chromatics* (1879), books that explore the physics of light, physiology of the eye, and psychological perception of color. However, the Neo-Impressionists came to different conclusions from Munsell. They tried to imitate the brilliance of the solar spectrum using Chevreul's rule of simultaneous contrast of colors,[48] placing small dots of color next to each other to optically mix when viewed at a distance. They used the complimentary colors these scientists described to make their colors appear as exaggerated as possible.[49]

Munsell's style was decidedly not Neo-Impressionist, but he and his artistic colleagues did not entirely conform to the old Academic style. Munsell was part of a group of painters in Boston who, according to Elizabeth Ives Hunter (the daughter of R. H. Ives Gammell, another École-trained Boston contemporary of Munsell), brought back to the States from their Academy training a "yeasty artistic ferment"[50] of the Academic and Impressionist styles, aiming to "solve the problems posed by plein air landscape"[51] but in a traditionally-minded way.

Though not many of Munsell's paintings are extant and reproductions are difficult to find, several seascapes show a realistic,

[32] Ratliff (1992), p. 23.
[33] Ratliff (1992), p. 29.
[34] Ruskin (1904 [1857]), p.192.
[35] Ruskin (1904 [1857]), pp. 192–3.
[36] Ruskin (1904 [1857]), p. 193.
[37] Ruskin (1904 [1857]), p. 229.
[38] Ruskin (1904 [1857]), p. 230.
[39] Rood (1879), p. 308.
[40] Boime (1971), p. 86.
[41] Boime (1971), p. 86.
[42] Gammell (1986), p. 29.
[43] Boime (1971), p. 166.
[44] See Brettell (2000) for a discussion of how speed was important to defining the esthetic of Impressionism. This idea that speed required in landscape painting reveals the "intrinsic nature" of the individual artist can be found on page 18.
[45] Boime (1971), p. 181.
[46] Brettell (2000), p. 18.
[47] Ratliff (1992), p. 155.
[48] Walther (2000), pp. 12–14.
[49] Signac (1921), quoted in Ratliff (1992), p. 213.
[50] Gammell (1986), p. 7.
[51] Gammell (1986), pp. 28–9.

yet somewhat loose style, as does his portrait of Helen Keller, hanging in the American Foundation for the Blind,[52] and his portrait of his father-in-law, Alexander E. Orr, in the New York State Museum, here reproduced (see Fig. 5). In this portrait, the loose and visible brushstrokes, especially on the highlights on the skin and in the hair and beard, are characteristic of an Impressionist influence. Such "unfinish" would not have been acceptable to an older Academic standard. However, the commitment to realism in capturing the likeness of the sitter and the muted color tones with extensive use of black are features that do not fit with the Impressionist or Neo-Impressionist esthetic, but are more in keeping with an Academic approach. Although the Neo-Impressionists' pointillist artwork looked very different from Munsell's more representational style, their tactic of studying color science surely influenced him, as he was in Paris while they were exhibiting.

Among traditionally trained artists, Munsell was not the only one who yearned for systematization of color. Ruskin reflected on the difficulty of naming colors: "You shall look at a hue in a good painter's work ten minutes before you know what to call it. You thought it was brown, presently you feel that it is red; next that there is, somehow, yellow in it; presently afterwards that there is blue in it. If you try to copy it you will always find your color too warm or too cold – no color in the [paint] box will seem to have an affinity with it."[53]

Munsell's ordered charts of labeled samples had precedent in some studio techniques. Ruskin advised systematically experimenting with mixing pigments and painting the results as labeled rectangles on a page before beginning work.[54] He also recommended an exercise for matching colors by viewing a landscape from a window through small holes in a viewing mask, reproducing the colors with paints and labeling what they referred to in the scene ("dark tree color," "hill color," etc.).[55] And Delacroix left practically a library of color swatches: pre-mixed samples for his large canvases that were labeled with their destinations in the composition.[56]

Several notes in Munsell's diaries point to his contemporaries' interest in solving these problems of color. An entry from December 10, 1903 tells of a visitor to the studio recounting "…school muddles about color – No teacher understands the subject of color – but everybody is interested in it – It is now the subject uppermost."[57] Munsell recorded many conversations about color with the artist Denman Ross: for example, in 1892 while sketching together in Italy they "talk[ed] over a systematic color scheme for painters, so as to determine mentally on some sequence before laying the palette."[58]

2.1. The Munsell System as a response to the art world

Munsell's diaries and published works show how his system was an answer in response to the color problems in the prevailing artistic climate. He was highly influenced by the Academic curriculum and its formalization of structure. Boime described the training in these schools as "a uniform system of instruction" with "strict adherence to formula."[59] The course of study brought students from the simple to complex; parts to the whole.[60] Students would begin by copying from two-dimensional examples, like Charles Bargue and Jean-Léon Gérôme's drawing course, proceed to drawings of plaster casts of antique sculptures, and finally begin drawing and then painting from the live model.[61] Both in the Académie Julian and the École there was a belief that strict training could make art objectively better – the goal being to closely mimic reality.[62]

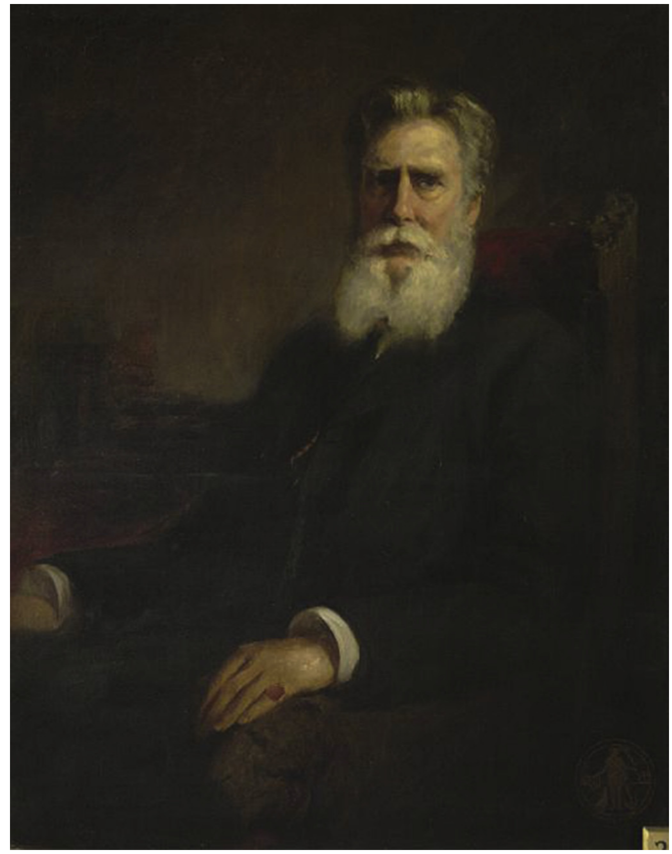

Fig. 5. Portrait of Alexander E. Orr (1903). This portrait demonstrates characteristics of Munsell's style that mix Impressionist influences with his Academic training. Image courtesy of New York State Museum, Albany, NY.

Munsell was keenly interested in a color system as a teaching tool for schools, and particularly school children.[63] The second half of *A Color Notation* (1905) is a description of a nine-year elementary school course about color.[64] Munsell's program for color education was heavily influenced by his experience with Academic art training, which we can see in comparison with Milton Bradley's outline for color education in his book *Elementary Color* (1895). Munsell's diaries show evidence that he studied Bradley's book,[65] which most likely influenced Munsell's work as the two men shared common goals of elementary school color education,

[52] American Foundation for the Blind, "Oil Painting of Helen Keller," 2013. <http://www.afb.org/section.aspx?FolderID=1&SectionID=1&TopicID=181&DocumentID=1054>.
[53] Ruskin (1904 [1857]), p. 228.
[54] Ruskin (1904 [1857]), p. 205.
[55] Ruskin (1904 [1857]), p. 207.
[56] Gage (1993), p. 186.
[57] Munsell diaries, p.134.
[58] Munsell diaries, p. 2.
[59] Boime (1971), p.18.
[60] Boime (1971), p. 19.
[61] Bartoli in Peck (2006) pp. 50–1. Also see Boime (1971), pp. 24–41; especially pp. 27 and 30.
[62] Weisberg and Becker (1999), p. 20.
[63] Nickerson (1940), p. 575.
[64] Nickerson (1940), p. 575. See Munsell diaries, p. 242, for examples of the educational leaders he was working with.
[65] Munsell diaries, pp. 7a–7b.

standardizing color names for effective communication, and bringing the color knowledge of artists and scientists together.[66]

However, where Bradley's outline of color education for children was probably challenging and confusing because he introduced color seen through glass prisms, spinning tops, and "tints and shades" in folded ribbons in the first lessons.[67] Munsell's course of study for children was built up from simple to complex, and focused on the abstract idea of pure colors rather than their physical correlates in the natural world. Just as the Academy deconstructed painting into fundamental skills that built on each other, so his color system breaks color down into its fundamental elements. His course of study required students to master the elements of color in levels of increasing difficulty, from memorizing the five primary hues to completing balanced compositions of three colors.[68] A note from February 1, 1909 in his diary reads that his goal was "To create a definite mental image of all color relations – To train the memory of color arrangements – (visualization and writing necessary for constructive imagination)."[69]

This quotation also shows Munsell's opinion about whether color was a matter of genius and originality, as he described his color system helping the "imagination." Imagination is usually thought of as a personal, innate skill, closely tied with the originality highly prized by the new non-Academy artists. But Munsell saw the ability to think and create color compositions – the color imagination – as being aided by a system. In *A Color Notation* Munsell laments: "Color harmony, as now treated, is a purely personal affair, difficult to refer to any clear principles or definite laws." He postulates that color harmony could be like musical harmony, which benefits from a notation system and rules of composition.[70] He writes: "Color needs a new set of expressive terms, appropriate to its qualities, before we can make an analysis as to the harmony or discord of our color sensations."[71] He argues that progress in creating beautiful color compositions would not come "from a blind imitation of past successes, but by a study into the laws which they exemplify."[72] In that spirit, Thomas Maitland Cleland, an American artist and illustrator, published a 1937 guide to mathematically using the Munsell alpha-numerical system to create pleasingly-balanced color compositions.[73]

Munsell also wanted his system to answer the difficulty of accurately matching colors from nature. He felt his system was an objective, rather than personal, measure of color – that it had been created experimentally and could be used consistently. He emphasized, "It does not rest upon the whim of an individual, but upon physical measurements made possible by special color apparatus. The results may be tested by anyone who comes to the problem with "a clear mind, a good eye, and a fair supply of patience."[74] This is in clear opposition to earlier ideas that people either do or do not have a knack for color.

To Munsell color did not depend on fleeting emotions. While Ruskin had commented that, even if you are blessed with good color sense, it will "depend much on your state of health and right balance of mind; when you are fatigued or ill you will not see colors well, and when you are ill-tempered you will not choose them well,"[75] Munsell compared color more practically to music, saying, "The musical scale is not left to personal whim, nor does it change from day to day; and something as clear and stable would be an advantage in training the color sense."[76]

3. Artistic insights in the Munsell Color System

The unique insights Munsell brought to studying color may have derived from his experience as a painter. His hands-on experimental approach to testing colors reflected his professional comfort with mixing paints; the École's course of study from simple to complex led him to think of color as consisting of separate variables of hue, value, and chroma; and the practical difficulty encountered when students each mix a wide variety of pigments to match, say, the same skin tone of a model may have encouraged him to think of color as dissociated from its "ingredients" – and therefore helped him to consider colors as independent "units" rather than thinking of their physical correlates.

Munsell's experimentation consisted not only of standard scientific practices using Maxwell disks and photometric readings, but also extensive *creation* of color through the paint mixing an artist must do. The system was a tool for his day-to-day profession, and so he began to create the physical samples concurrently with his theoretical research. Munsell was personally involved in the manufacture of his color charts from the very beginning, as entries in his diaries attest.[77] His first attempts at fabricating his system began before he had even worked out many of the particulars: by 1900, for example, Munsell had already produced six-inch diameter model color spheres.[78] By 1901 he had completed charts of colors at value 5 and value 6.[79] And in 1901–02, he had painted chroma scales by visual estimates,[80] even though it took until 1912 for him to settle on a method for making the chroma scales.[81] It was during these years of attempting to create charts that he discovered the irregular nature of chroma. An enthusiastic 1906 diary entry reads, "Chroma would seem to diminish arithmetically and value geometrically!!"[82]

A similar trial-and-error, hands-on experimentation process led to his choice of primary hues. In 1901 Munsell had not yet decided whether to use three or ten hues[83]; the evidence from color-matching experiments by scientists like Abney and König strongly suggested three primaries.[84] But he decided on five for the convenience of the decimal system, and determined the hues by the practical test that they balance to neutral gray on Maxwell disks. For his value scales, Munsell first solicited visual judgments from

66 Bradley (1895), 11–12.
67 Bradley (1895), pp. 76–87.
68 A chart of the nine-year lesson plans shows how the subject matter increases in difficulty from the principle hues in the first year through the values, then chromas, and finally to compositions of triads of balanced colors, while the materials increase in sophistication from crayons and paper to building color charts, a color tree, and finally using paints. See Munsell (1907 [1905]), p. 100.
69 Munsell diaries, p. 247.
70 Munsell (1907 [1905]), pp. 10–11.
71 Munsell (1907 [1905]), pp. 27–28.
72 Munsell (1907 [1905]), p. 47.
73 *A Practical Description of the Munsell Color System with Suggestions for its Use* was originally published as an addition to *A Grammar of Color* (1921) published by Strathmore Paper Company. For a description of the mathematical formulas, see Cleland (1937), p. 17.
74 Munsell (1907 [1905]), pp.10–11.
75 Ruskin (1904 [1857]), pp. 230–1.
76 Munsell (1907 [1905]), pp. 24–5.
77 See Munsell diaries, pp. 274, 373, and 382 for some examples.
78 Kuehni (2002), p. 22.
79 Kuehni (2002), p. 26.
80 Munsell, obviously, did not make every color sample himself, especially after the system became marketable. However, he painted the first experimental samples himself, and there is documentation that he at least supervised and directed the painting of the original charts in his own studio by a Mr. Lyon, with "all colors being checked by Mr. Munsell" (Nickerson (1940), p. 578).
81 Nickerson (1940), p. 576.
82 Munsell diaries, May 7, 1906, p. 199.
83 Nickerson (1940), p. 576.
84 Kuehni (2002), p. 25.

"artists, dyers, salesmen and students"[85] and simple photometric readings before inventing his cats-eye photometer.

A craftsmanly drive to create his samples as he researched does not fully explain his unique conception of color, however. The particular training Munsell received at the Académie Julian and the École des Beaux-Arts in the 1880s may have influenced his system in deeper ways than a mere familiarity with paints, which Ogden Rood and William Ostwald (whose color systems I will discuss in part 5 of this paper) both had as amateur painters.

The course of education at the École and associated ateliers separated value modeling from hue/chroma modeling by having students master one (drawing) before attempting the other (color painting). This background may have been the source of Munsell ability to think of hue and value as separate variables when creating his color system. The Academic course of study usually began by drawing plaster casts of ancient statues.[86] As the plaster casts were white and the drawings were done in charcoal or graphite, these exercises removed the variable of hue to focus the student on understanding value.[87] Often, after students had mastered drawing, they painted the nude model in grisailles (shades of neutral gray), an exercise that would force them to determine values without being confused by colors in the skin.[88] Finally students would progress to full color painting. A diary entry from 1904 demonstrates that this education influenced Munsell's conceptual separation of the variable of value. He wrote, "The present solid grew from the little twirling model of 1879: in which Value was paramount (the artistic foundation of color,) not wave-length."[89]

Color painting instructions related by the artist R. H. Ives Gammell also suggests a practice that would help to conceptually separate the three variables of color. Ives Gammell quotes his teacher (and fellow Boston artist) Edmund Tarbell as saying, "Give each little area of the painting its own paint, right in hue and value, without further modification from or into adjoining areas. The method is akin to that of the mosaic. Halftones are to be painted as halftones, not mixed on the canvas by pulling a dark stroke into a lighter."[90] This admonition not to blend colors on the canvas was also common to the academies,[91] and Ruskin provides the same advice in his *Elements of Drawing*.[92] Such a technique required the painter to carefully mix each color he put down, much as Munsell considered each color sample as a separate unit or, as he called it in his diaries, a separate "co-ordinate" [93] of color.

Finally, a dilemma in any atelier is that many students work from the same model, but try to arrive at similar colors through different pigment mixtures. Teachers have to adjust the students' paintings without necessarily knowing what went into each blend of colors, but by understanding how additional pigments will alter a mixture. For example, ivory black will *darken* a mix while also *cooling* the hue and lowering the chroma (making it *weaker*). Munsell seems to have been aware of this traditional way of understanding color, as early on in his diaries he described "Three qualities" of colors: "light and dark, hot and cold, weak and strong."[94] These were the features he used to divide his "color score," a paper chart he recommends making in *A Color Notation* to quickly record pleasing color combinations in a graphical space.[95] This everyday painter's task of adjusting color mixtures based on the predicted change a pigment will make, but without knowing the "formula" of the original mixture, may have contributed to Munsell's unique ability to remain agnostic about what makes up a color and instead to analyze it based on its "coordinate" attributes of hue, value, and chroma.

4. The problems of color in the scientific world

While artists were struggling with whether color could be objectively taught, scientists were struggling with the definition of color. "Color" lies at the intersection of psychology, physiology, and physics: it is a psychological perception generated by physiological action of the eye and nerve cells in response to the properties of physical light. In the nineteenth century, the diverging experimental methodologies and research interests of the different disciplines made color a topic of heated debate. Though early experimental psychology had shared many of the same experimental methods and concerns as physics and physiology,[96] by Munsell's time there was an epistemological divide between physicists and psychologists.

Physicists measuring light and color preferred machine-collected data of phenomena unobservable with the naked eye[97] because of the objectivity, precision, speed, and automation of such instruments.[98] Psychologists, meanwhile, had become interested in discovering how complex mental processes happen.[99] In America, where Munsell was working, psychology was shaped by Darwinism, an interest in individual differences, and intelligence testing.[100] Out of this mix came the Functionalists,[101] who not only aimed to explain higher-order cognition like thoughts and beliefs by understanding how the mind had evolved, but also promised useful applications for mental health, business, and education.[102]

The divergent approaches of the physicists and psychologists Munsell worked with have strong parallels with the development of "objectivity" in the nineteenth century as described by Lorraine Daston and Peter Galison in their 2007 book *Objectivity*. The physicists' interest in the mechanical recording of the Munsell photometer parallels what Daston and Galison describe as the epistemology of "mechanical objectivity," or the concern for controlling the subjectivity of the human observer.[103] The way Munsell standardized his procedure and kept diary records of his

85 Munsell (1912), p. 236.
86 Boime (1971), pp. 27 and 30.
87 Boime (1971), p. 30.
88 Speed (1926), p. 140, describes the difficulties a student may encounter when first attempting to determine value from a live model.
89 Munsell diaries, November 4, 1904, p. 167.
90 Tarbell quoted in Gammell (1986), p. 27.
91 Boime (1971), p. 38.
92 Ruskin (1904 [1857]), p. 209.
93 Munsell, diaries, December 7, 1905, p. 187.
94 Munsell, diaries, p. 88.
95 For a description of the color score, see Munsell (1907 [1905]), p. 83.
96 Daston and Galison (2007), pp. 263–5 provide an interesting discussion of how Wundt's experimental psychology was "objective" along the same lines of natural philosophy. Boring (1929), p. 657 provides a history of experimental psychology from its early primarily physical and physiological concerns to the later work on higher-order processes. He also discusses the "orthodox experimental psychology" of Wundt on p. 377.
97 Johnston (2001), p. 58, describes how "[a] transition was occurring, among physicists at least, from acceptance of visual methods of observation to a preference for physical methods."
98 Johnston (2001), p. 126, writes that "[b]y the First World War, nearly all practitioners [of photometry]…sought a physical alternative to the eye."
99 Boring (1929), p. 657, provides a history of experimental psychology from its early primarily physical and physiological concerns to the later work on higher-order processes.
100 Boring (1929), p. 494, gives a brief overview of American psychology in the early twentieth century.
101 Schultz and Schultz (2011), p. 103, call Functionalism "the first uniquely American system of psychology."
102 Pickren and Rutherford (2010), p. 84.
103 Daston and Galison (2007), chapter III.

research recalls the training of the scientific self that they describe.[104] And the repeatability of his experiments conforms to the extension of their definition of "mechanical objectivity" into the automation of the scientist's actions.[105] But rather than attempting to read the entire narrative of scientific discourse on color through the lens of Daston and Galison's argument, or trying to determine how Munsell's color atlas fits into their history of scientific atlases, I will focus on analyzing the primary documents left by Munsell to reveal the attitudes of his scientific colleagues toward his experimental methodology and resulting color system.

The Munsell System can be seen as a workable compromise between the different scientific fields; it was well suited as a tool for psychological experimentation, while physicists could also accept it due to its quantitative, measureable, and replicable nature as the best option until further advances in vision science made physical specification of color matching possible.

Munsell was able to establish contact with many researchers at major institutions, especially on the East Coast of the United States, through mail, personal appointments, and by attending lectures. Munsell kept a studio in the Back Bay section of Boston and taught at the Massachusetts Normal Art School (now Massachusetts School of Art),[106] and therefore was in close proximity to Harvard and M.I.T., which may have aided in his ability to connect with professors there such as Robert Yerkes, Henry Pickering Bowditch, H. E. Clifford, and Professor C. R. Cross. His diaries contain letters from professors demonstrating written correspondence.[107] He attended lectures at these universities and was invited, in turn, to give lectures.[108] And the diaries are littered with notes from many face-to-face conversations. Munsell recorded having appointments or meals[109] with these men, often in their laboratories and offices or in his studio. And he met and talked with the psychologist Christine Ladd-Franklin while aboard a ship returning to the United States.[110]

The conversations with scientists that Munsell recorded in his diaries show a rift between physicists and psychologists on the topic of color. As early as 1900, Munsell quoted Prof. Cross of MIT as saying that the Munsell System "establishes an idea of color based on something fixed. A matter of psychology – rather than physics."[111] This statement draws a line between how the two fields thought about color, but later entries reveal greater tensions: in May of 1913 Christine Ladd-Frankin gave a series of lectures that Munsell attended covering "The Rival Color Theories and their Commonly Suppressed Consequences," in which she delineated the topics of: "The Physical Theory of Color (Young-Helmholtz) – The Physical Theory (Hering) – The…Psychological Theory (Ladd-Franklin)."[112] In a personal conversation with Ladd-Franklin Munsell noted that she wished "first to present this idea, which is ignored by the physicist," that it is wrong to say that "yellow is made of red and green, but only that yellow light can be made out of red and green light, though it may equally well be homogeneous."[113] In this statement, Ladd-Franklin was insisting on separating the color *experience* from the *physical light* that produces it, and was delineating between the psychologists' and physicists' definitions of color. This is similar to a comment Edward Titchener made to Munsell in November of 1910, that his own model was psychological, while "[the] physicist tries to ignore the eye – (physiologic action)."[114]

From Munsell's correspondence, we can see how psychologists needed to answer complex questions requiring introspection, but wanted to regulate this introspection through strict protocols using controlled, external measures. Milton Bradley commented in his book *Elementary Color* that "With the establishment of professorships of practical psychology and the equipment of laboratories, provided with delicate and expensive apparatus for making and recording tests, there comes with increasing force the demand for some means by which the experiments in color made in various localities may be unified both as to the colors used and the terms and measurements for recording the result."[115]

The Munsell System, with its standardized samples containing all of the complex color perceptions divided into their three simplest variables, could be a measuring tool for those kinds of psychological experiments. As an example, Munsell recorded in his diary in January of 1912 that the psychologist Robert Yerkes did a study using Munsell's five middle colors to test the "affective" values of the colors on eighteen women and thirteen men.[116] Similarly, the standardization offered by the Munsell System could be seen as useful for the American interest in testing individual differences. For example, Munsell recorded Henry Pickering Bowditch as wanting to use Munsell"s photometer for "a quantitative measure of color blindness, "so as to say that a certain individual has only such a percent of normal sensibility to a given color."" [117] (Today the Munsell Color Company sells color vision tests based on Munsell colors.[118])

The Munsell System was also useful for education, a topic Pickren and Rutherford say became a fruitful area for the application of psychological research.[119] One of Munsell's lectures at MIT was entitled "A Measured Training of the Color Sense,"[120] reflecting his intention that the system be used "to train the memory of color arrangements."[121] Munsell spent much time preparing lessons, charts, and art supplies to aid in teaching color to children, and worked with people in the educational field to try to implement his ideas.[122]

The design of the Munsell system made it particularly useful for applications in industrial efficiency.[123] For example, an October 6, 1910 diary entry reads: "Prof. Yerkes (Harvard) calls me up to ask if the publishers will loan the color charts and color sphere for his

104 Daston and Galison (2007), chapter IV, and also particularly pp. 52 and 44.
105 Daston and Galison (2007), p. 121 for a definition of "mechanical objectivity" that extends to a set of procedures.
106 Nickerson (1940), 575.
107 For a few examples of many in the diaries, see Munsell diaries, May 7 and 10, 1900, p. 30 for correspondence with Ogden Rood, and February 15 and 19, 1901, p. 54 for correspondence with H. E. Clifford.
108 Nickerson (1940), 576–577.
109 For one of many amusing examples filling the diaries, Munsell recorded having "lunch at Victoria" with Prof. Clifford on Nov 13, 1900. Munsell diaries, p. 41.
110 Nickerson (1940), p. 577.
111 Munsell diaries, May 14, 1900, p. 30.
112 Munsell diaries, May 12, 1913, p. 372. The original text reads "The Psycho-Psychological Theory (Ladd-Franklin)," which is perhaps a typo for "The Physio-Psychological Theory."
113 Munsell diaries, p. 237.
114 Munsell, diaries, November 18, 1910, p. 281.
115 Bradley (1895), p.8.
116 Munsell diaries, p. 310. Munsell samples have also been used as standard colors in other psychological experiments since then, notably Berlin and Kay's famous 1969 experiment determining the eleven basic color terms across cultures. (Kaiser and Boynton (1996), p. 498).
117 Munsell diaries, Dec, 1901, p. 84.
118 http://munsell.com/color-products/color-vision-tests/.
119 Pickren and Rutherford (2010), pp. 85–6.
120 Munsell diaries, Nov 14, 1909, p. 241.
121 Munsell diaries, Feb 1, 1909, p. 247.
122 See Munsell diaries, p. 242, for examples of the educational leaders he was working with.
123 Pickren and Rutherford (2010), p. 88, discuss the interest in industrial efficiency and the psychological applications for it in America.

– to be given at Johns Hopkins Psychological Laboratory in Baltimore…They should be sent care of Prof. J. B. Watson."[124] The color chips make identifying colors of products feasible, and the alpha-numerical notation system makes communication efficient and consistent.

The benefit of a standard, reliable color ordering system for applications in science, education, and industry can be seen as an attraction to both sides of the debate over the definition of color. Munsell was aware of this advantage, and described his work to the American Psychological Association as "a sound mathematical basis for the description, comparison and classification of colors," which could therefore be "an instrument that may be of use to psychologists."[125]

While psychologists embraced the Munsell System as a tool for experimentation, diary entries suggest physicists could accept it as an adequate compromise because of its reliance on the photometer, quantitative nature, and repeatable results. In April of 1900 Munsell wrote that Amos Dolbear, a physicist at Tufts University, praised Munsell for "arriv[ing] at a higher degree of accuracy and convenience than any methods hither devised."[126] We can assume that Dolbear considered it "accurate" because it was quantified and based on multiple tests, while it was "convenient" because of its alpha-numerical structure. Elsewhere in the diaries Munsell reported Dolbear's praise of the system as "beautiful…because [it is] based on physical tests,"[127] saying, "it eliminates the personal bias (that would make it a private matter)—and is an approach to a standard that can be depicted at will by numbers."[128]

Munsell's experimental methodology, however, pushed the limit of what was acceptable to physicists who distrusted "personal bias." While Munsell's experimental methods avoided the obvious problems of quantification and repeatability of purely introspectively derived color systems like Herring's four primary colors (which were popular among psychologists),[129] he did rely, ultimately, on human observations and visual judgments. Maxwell disk experiments were repeatable between observers and provided numerical results, but also fundamentally relied on the eye. His diaries are filled with pages of repetitions of experimental data; measurements of samples taken by himself and almost anyone, it seems, who visited his studio. Moreover, each of these trials relies on the human judgment of "neutral gray" – a problem not explicitly raised by Munsell or his contemporaries, but undertaken in the 1920s following Munsell's death by his son, A. E. O. Munsell, who partnered with Irwin G. Priest of the Bureau of Standards on several experiments to establish a standard white light and a determination of gray.[130]

The one purely mechanical aspect of the Munsell System is the value scale, determined by readings from the photometer he invented. That the value scale is directly correlated with reflectance – a property of physical light – may seem to contradict the claim that Munsell did not tie his color system to physical correlates of color. However, since the design of his "cats-eye" photometer accounted for the Weber-Fechner law of sensation in the perception of brightness, the photometer can be seen as the bridge between the psychologists and physicists. It was a mechanical check – something that would have appealed to physicists – for a psychological concept.

The legitimizing power of the photometer is demonstrated by the interest physicists took in it. Not only did the department of Optical Measurements at MIT adopt his photometer for several years,[131] but Munsell was invited to give talks at the Math and Physics club at MIT, often with particular emphasis on the photometer.[132] The introduction to *A Color Notation*, written by H. E. Clifford, then the Gordon McKay Professor of Electrical Engineering at Harvard University,[133] emphasizes how the photometer made the system "scientific." He writes, "In the determination of his [Munsell's] relationships [of color] he has made use of distinctly scientific methods…The Munsell photometer, which is briefly referred to, is an instrument of wide range, high precision, and great sensitiveness, and permits the valuations which are necessary in his system to be accurately made."[134]

Munsell understood the fundamental importance of a reliable value scale. He wrote in *A Color Notation*: "Since this value scale underlies all color work, it needs accurate adjustment by scientific means, as in scales of sound, of length, of weight, or of temperature."[135] In his procedure all color samples, not just the neutral value scale, were tested with the photometer. Therefore it provided a mechanically-checked backbone around which he could hang the rest of his color measurements.

As previously discussed, the photometer bridged the physical/psychological divide with its shutter designed to account for the Weber–Fechner law of sensations. But its design also translated the physical property of "brightness," the perceived level of emitted light (a physical property) to the psychological sensation of "lightness," the judged relationship between regions (a psychological property).[136] In the Munsell photometer a painted sample is placed in one half of the viewing field (an example of "lightness") and compared with white light in the other half, dimmed with the cats-eye shutter (the "brightness" of physical light).[137]

However, Munsell's method was still a compromise: Clifford did not consider the system perfect. In his introduction he writes, "There seems no reason why his suggestions should not lead to an exact and definite system of color essentials,"[138] implying that the rigor could be improved. Similarly, Munsell recorded a hesitant Dolbear as saying, "…this sphere lacks perfection from a physical standpoint, (source and nature of light should be defined as well as its reflection)."[139] We have seen that Dolbear approved of the numerical results and eliminating "personal bias" – the very thing machine data collection is meant to do. But the system was only "an approach to a standard." It was not perfect to Dolbear because it ignored the physical light source.

The debates about how to define color were international and did not end with the publication of Munsell's system. The arguments came to a head during meetings of international commissions to standardize color in the 1920s and 30s.[140] The stalemate

124 Munsell diaries, p. 276.
125 Munsell (1912), p. 244.
126 Munsell diaries, p. 15.
127 Munsell diaries, p. 111.
128 Munsell diaries, pp. 41–2.
129 Turner (1994), pp. 177 and 181.
130 See a list of these publications on the definition of gray in Nickerson (1940), p. 581.
131 Munsell diaries, April 27, 1903, p. 132.
132 Munsell diaries, Feb 15, 1901, p. 54; Apr 27, 1903, p. 129. Oct 27, 1904, p. 166, Nov 4, 1904, p. 167.
133 Nickerson (1940), p. 69.
134 Clifford, introduction to Munsell (1907 [1905]), p. 5.
135 Munsell (1907 [1905]), p. 38.
136 Shevell (2003), p. 162.
137 Munsell (1907), p. 39.
138 Clifford, introduction to Munsell (1907), p. 5.
139 Munsell diaries, pp. 41–2.
140 The International Commission on Illumination, or Commission Internationale de l'Éclairage meetings.

between the physical and psychological definition of color in the Optical Society of America (OSA) meetings reached such a degree that, as Johnston writes, "the committee delegated Deane Judd, the principal spokesman for psychology, and Arthur Hardy, representing the perspective of physics to give final approval to the report."[141]

However, Munsell's system was a part of the eventual compromise between physicists and psychologists: the OSA and then the International Commission on Color (abbreviated CIE for the French, "Commission Internationale de l'Éclairage") adopted a psychophysical definition of color.[142] Munsell's system accorded well with this definition, and a formula to translate between Munsell values and the official CIE tristimulus values was published after the meetings.[143]

The fact that Munsell actually created the samples making up his system, unlike the other scientific color researchers of the time, meant the system could be physically tested with spectrophotometers, recorded, and refined with advances in our understanding of color.[144] And indeed changes to the Munsell samples have been made over the course of the century, in a dialog of physical tests and visual judgment. In 1940, for example, the OSA formed a committee to evaluate the spacing of the Munsell colors.[145]

In this way, the Munsell System became a meeting-ground for psychologists and physicists: it described an internal (essentially psychological) color space resting on a photometrically-tested value scale, quantified and embodied in physical samples that could be refined both with spectrophotometric and visual testing.

5. The Munsell System in context: three examples of contemporary color systems

Why did the different disciplines not simply develop independent color systems, but instead choose a compromise? To answer this question I compare Munsell work with the work of three scientists in the early twentieth century: Wilhelm Ostwald, a Nobel-Prize winning chemist; Ogden Rood, professor and Chair of Physics at Columbia University; and Edward Bradford Titchener, a student of Wilhelm Wundt and professor of Psychology at Cornell University. These comparisons are especially relevant because Munsell consulted with these men: Munsell met Ostwald when he visited Boston to give lectures at MIT in 1905, during which time Ostwald also visited Munsell studio; he recorded frequent conversations and written correspondence with Ogden Rood in the diaries, beginning with the first meeting on March 29, 1900; and he attended several of Titchener lectures at M.I.T in November of 1910 (after which he recorded having supper with many professors at the lectures).[146]

Though these men also created three-variable color systems, Munsell's system has unique features that account for its success in real-world applications of science, art, and industry, because it provides an ordering system that can be learned and used with minimal training. These unique features are independently functioning variables of color, allowing the user to systematically adjust a color sample when matching, and perceptually uniform scales of these variables, making it easier to guess at the amount of adjustment necessary.[147] These features also lead, experimentally, to the construction of an irregularly shaped color solid that more accurately describes our color experience than the elegant but preconceived geometrical arrangements of competing systems.

Most of the insights that led to the unique features of the Munsell System were well known before Munsell began his work, including some irregularities of color perception and the limitations of using physical lights, pigments, and psychological introspection. For example, Munsell noted in his diary that physicists knew of the different apparent lightnesses of maximally saturated hues.[148] Debates about the spacing of hues and which were "primary" had raged for decades, especially between Helmholtz and Hering.[149] And the downsides of using pigments and spectral light for color research were well known,[150] as these three contemporary scientists' reliance on several media for experimentation prove.

Yet a glance at the color systems of the nineteenth and twentieth centuries compared with Munsell emphasizes how radically different his color solid looks (see Figs. 1 and 2), so we must account for this drastic difference in end result.

5.1. Ogden Rood: colors as spectral color

Rood defined color in terms of the physical properties of light. This prevented his system from fully mapping human color perception, and led him to describe his three variables of color as affecting each other, rather than being independent. Without independent variables, he could not create perceptually uniform scales of color. The reliance on physical light also made his system impossible to manufacture or use in practical applications.

Rood's three variables, or as he calls them in *Modern Chromatics* (1879), "constants of color," are hue, luminosity, and purity (pp. 209–10). While these seem similar to Munsell's hue, value, and chroma, they are defined more strictly in terms of spectral light. Rood writes, "…our pure standard colors are to be those found in the spectrum" (p. 31), and he defines hue "…as the physicist would say, [as] the degree of refrangibility, or the wave-length of the light" (p. 36). Even though Rood also experimented with colored papers on Maxwell disks, his methods show that he fundamentally conceived of the definition of "colors" as lights: he describes adding white to the paper samples by reflecting white light from a mirror onto the paper (p. 32), and determines what colors are present in a sample by passing light reflected from the paper through a prism

141 Johnston (2001), p. 181.

142 Johnston (2001), p. 181. The definition from the 1939 meeting reads: "Color consists of the characteristics of light other than spatial and temporal inhomogeneities; light being that aspect of radiant energy of which a human observer is aware through the visual sensations which arise from the stimulation of the retina of the eye."

143 Nickerson (1977b [1975]), p. 8.

144 Landa and Fairchild (2005), p. 441, explain; "Although the colors of the Munsell system are specified by their appearance in terms of value, chroma and hue, once samples for each designation are created, the system can be recorded and reproduced using physical metrics of color. Specifically, the spectral reflectance of the samples and the spectral power distribution of the illumination are used together with standard human response functions to designate physical color coordinates known as tristimulus values, which are directly related to the stimulus wavelength and energy. These coordinates ultimately define the system and allow reproduction of nominal-color samples. Such numerical color specifications allow the system to continue to be recreated even if the samples of a current embodiment should fade or be otherwise damaged."

145 Described in detail in Newhall (1940).

146 Munsell heard a series of talks by Ostwald and subsequently met personally with him in 1905 (Munsell diaries, pp. 187 and 189); he attended Titchener lectures on the Structure of Mind at MIT in 1910 and met with him on occasions afterward (Munsell diaries, p. 278); and Munsell not only read Ogden Rood's *Modern Chromatics* (Munsell diaries, 1879, p. 1) but seems to have worked closely over several years with Rood, as he made frequent references to conversations with him in the diaries (Munsell diaries, p. 39, for one example of an interview).

147 A similar analysis is provided by Bond and Nickerson (1942), p. 718, in comparing the Munsell and Ostwald systems.

148 Munsell, diaries, Apr. 30, 1902, p. 107.

149 Turner (1994) for an account of the debate between Helmholtz and Hering about (among many other things) primary hues in the nineteenth century.

150 Rood (1879), p. 209, mentions this fact.

(p. 211). For contrast, when Munsell altered a color sample, he worked within the system itself; for example he describes adding "middle gray" (of value 5) to a red pigment to lower the chroma, without referring to the gray as paint to be mixed in.[151]

It is tempting to try to scale a color system to the physical properties of light, as they are measureable and quantifiable, and have a general correlation with our experience of color. The different wavelengths appear different hues; intensity is correlated with brightness or lightness; and purity of the wavelength is correlated with chroma. Rood explicitly appeals to these characteristics of physical light as the reason to focus on them when studying color in *Modern Chromatics* (p. 213). However, the relationship between our perception of color and the stimulus of light breaks down in certain ways that cause problems for a purely physical color system.

While the wavelength of light correlates with hue, wavelength alone will not reliably predict the perceived color and cannot represent a whole range of color perceptions. The phenomenon of color constancy is an illustrative example: we perceive a tomato as red even if the wavelengths it is reflecting, due to the lighting conditions, are very different from "red" in standard lighting conditions. Furthermore, more than one wavelength or combination of wavelengths can appear the same hue, a phenomenon known as metameric matching. Spectral colors also cannot account for all the colors we perceive: colors like brown, beige, and olive green are surface colors and cannot be perceived with isolated lights.[152] Finally, equal differences in wavelengths will not necessarily correspond to equal differences in perceived hue, so if the amount of space each hue is allotted in the system is strictly aligned with the wavelengths of the spectrum, the color solid will appear unbalanced, meaning it will appear to have an excess of certain hues (or in Munsell system, will not spin to neutral gray).[153]

The conceptual framework of color as physical light prevented Rood from describing his constants of color as fully independent variables. By defining hue strictly as wavelength Rood had to track how the perceived hue changed with increasing intensity. Not only can lighting conditions appear to alter the hue of an object, but because of what is called the Bezold–Brücke hue shift, even isolated spectral lights can appear to change hues as the intensity of the isolated light increases. Rood devotes all of Chapter XII of *Modern Chromatics* to "The Effect Produced on Color by a Change in Luminosity, and by Mixing it with White Light."[154]

Rood's conception of color as physical light also led him to use terms beyond the three variables when describing color sensations, further confusing the systematic ordering of all color perceptions by tying different variables together. For example, he introduces terms such as "intensity" and "saturation." He says, "Colors are often also called intense, or saturated, when they excel both in purity and luminosity…Purity and luminosity are, then, the factors on which the intensity or saturation depends. We shall see hereafter that this is strictly true only within certain limits, and that an inordinate increase of luminosity is attended with a loss of intensity of hue or saturation."[155]

A Munsell diary note provides further evidence regarding Rood's mindset about color: he quotes Rood as saying, "Saturation is a combination of (chroma and value) in their highest degrees…a color is saturated if it – is perfectly pure – and perfectly bright."[156] Rood not only preferred to think of color as physical light (to which the terms "intensity," "purity," and "brightness" refer), but his notion of purity – one of his constants of color – was *defined* as varying with both brightness and saturation. These other color sensation terms unnecessarily complicated his system, for if they are combinations of the constants of color, they should be described instead only by those fundamental variables.

We can see Munsell's separation of the three variables in the structure of his system and the samples he created, but evidence that this separation was reflected in his mental processes may be found in his sequence of directions for creating a color solid in *A Color Notation*.[157] To make a color sample, each variable is treated independently: first hue is considered, and a pair of pigments representing complimentary hues is painted on the Maxwell disks. Their relative areas on the disk are adjusted until they appear neutral gray when spun. Next chroma is adjusted by adding the necessary amount of neutral gray to the appropriate hue sample. Throughout, their values are double-checked with the photometer, and darkened or lightened as needed.

In practice, we can only accurately record the rate at which we perceive changes in color by altering one variable at a time. By not having independent variables, Rood's system failed in that measure. Rood himself admitted the impracticality of his double-cone system, writing that it would be impossible to execute with pigments.[158]

5.2. Wilhelm Ostwald: tracking color mixtures like pigments

Ostwald worked with Maxwell disks, the spectral reflectances of pigments, and Herring's introspectively derived four primary colors,[159] but his system implicitly defined color in a way that recalls mixing pigments, perhaps because Ostwald was not only a chemist but an amateur painter.[160] His conception of colors as pigments was not explicit, however: he chose the number of hues in his system for practical reasons[161] and notes that white and black are only "ideals" and cannot be represented with paints.[162] Yet the way he defined color was based on the composition of each mixture, which prevented him from creating perceptually uniform scales.

Ostwald's system refers frequently to pigments, their spectral measurements, and how they mix. The hue circle was defined by "ideal pigments" and their wavelength ranges.[163] And his three variables of color were the proportions of white, black, and full color in a sample, described by the equation; $C + B + W = 1$.

The problem with Ostwald's definition of color is that it essentially labels the color sample before its qualities are analyzed: he kept track of what went into the mixture rather than plotting and labeling the colors after analysis, as Munsell's method did. In fact, colors mixed with the same amounts of black and white will often not appear equally light or dark, and equal amounts of black and white will not appear to lighten or darken a mixture at a uniform rate. For example, add equal amounts of black paint to yellow and blue paints and the yellow mixture will appear lighter than the blue mixture.

151 Munsell (1907 [1905]), p. 69.
152 Shevell (2003), p. 164.
153 This can be scientifically measured with wavelength discrimination functions, as in Kaiser and Boynton (1996), pp. 315–6.
154 Rood (1879), pp. 181–201.
155 Rood (1879), p. 39.
156 Munsell diaries, p. 102.
157 Munsel (1907 [1905]), pp. 66–70.
158 Rood (1879), pp. 217–8.
159 Bond and Nickerson (1942), p. 712.
160 Bond and Nickerson (1942), p. 709.
161 At first he made a one-hundred hue circumference but then decided on a twenty-four hue circumference for practical purposes. Bond and Nickerson (1942), p. 53.
162 Bond and Nickerson (1942), p. 710.
163 Rather than reflecting a single wavelength, these ideal pigments would reflect through a range of half the spectrum, and their ideal complementary would reflect the other half. Bond and Nickerson (1942), p. 712.

In contrast, the value of a color sample in the Munsell System was judged without regard to its content: yellows of value three are made to appear equally dark as blues of value three. The Ostwald system, tied to inputs, does not have perceptually uniform steps across all hues, making identifying and adjusting colors more difficult than with the Munsell System.[164]

While Munsell also relied on pigment mixing to create his samples, it did not conceptually permeate his system. Munsell claimed to use "reliable pigments…whose fading is a matter of years and so slight as to be almost imperceptible" preserved in "imperishable enamels." However, this statement was a defense meant to advertise the reliability of his product: these colorants were intended to "[meet] the most serious objection to a pigment system."[165] In essence, Munsell was actually assuring his audience that pigments were *not* fundamental to his system.

5.3. Edward Bradford Titchener: color as a physiological response

Titchener's three-dimensional solid is more influenced by psychological work than Rood's or Ostwald's: it is an octahedron with a quadrilateral axis of hues based on Herring's introspectively found primaries, tilted to describe how certain hues appear lighter than others (see Fig. 6). Titchener discovered many of the irregularities of color perception that Munsell's system describes: that the rate at which one hue changes to the next does not correspond to wavelength; that different hues reach different maximal chromas; and that certain hues appear lighter than others.[166] However, Titchener's color system was not precise about these irregularities; there is no indication of *how* much brighter yellow appears than blue, and therefore his resulting color solid has a smooth, idealized contour.

The Munsell System achieves such quantification through his system of alpha-numerical labeling: for example, the most chromatic yellow has a specific number for its value that measures how much lighter it appears than the most chromatic blue. Since the variables are independent, all samples with a value of 3, for example, will appear equally dark, though they may be red or green, nearly neutral or highly chromatic. Since the axes are perceptually uniform, the magnitude of difference between any two adjacent steps along one axis is perceived to be the same, so the difference between color samples can be mathematically compared.[167]

Titchener may not have made this leap to quantification because he considered the study of mental phenomena to be psychophysical. Titchener classified colors as "sensations,"[168] and therefore may have been biased to conceive of them as following the Weber–Fechner Law, which Titchener esteemed as "the first law, in the scientific meaning of the word, discovered by psychology."[169] While this mindset might make it seem that Titchener would have quantitatively measured color perception, it led Titchener to describe, based on introspection, the "stimulus–response curves" along only certain paths in the color solid. For example, he

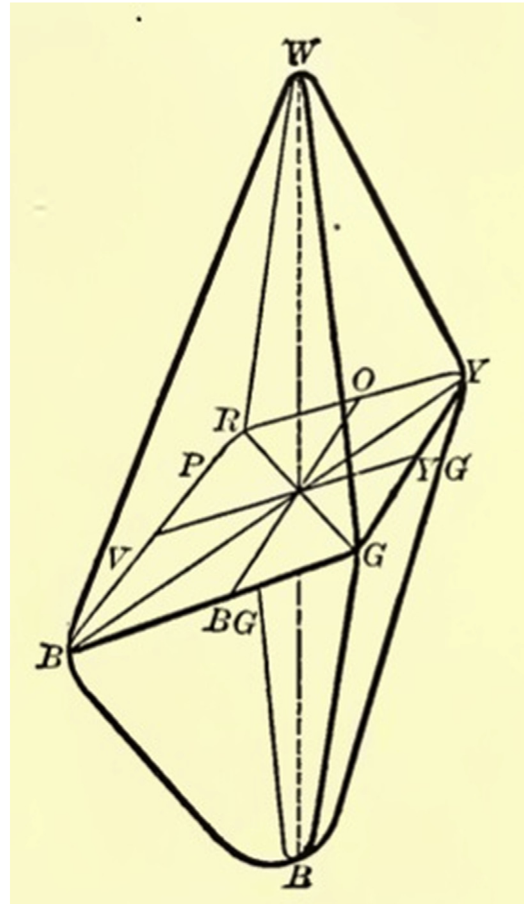

Fig. 6. Titchener's color solid. Unlike previous color solids, Titchener's was tilted to reflect some irregularities of color perception. Image from Titchener (1928 [1896]), p. 63.

described "drawing lines" (imagining how the sensation would change) along each hue as it changed in lightness.[170] This method does not create a scale to relate the lightness or darkness between all hues and chromas (or to relate chroma levels of all hues and values), and therefore cannot quantify the difference between two samples.

Munsell, on the other hand, found his colors by spinning opposite hues together on a Maxwell disk to balance them.[171] This forced him to work piece-by-piece, plotting colors at their correct distances away from neutral gray and comparing opposite sides of the solid, with seemingly unrelated colors, at once. As evidence of this graphical thinking, Munsell explained that the shape of his solid had to be "in accordance with the "co-ordinates" of the pigments,"[172] which suggests that he may have been thinking of his color samples as plotted points. This method also gave him a way to quantify differences, as he could measure the relative areas of each color on the disk after it was balanced, thereby assigning a number to their respective chromas.

Finally, Titchener's introspective approach was not repeatable between observers: introspection necessarily relied on the inner experience of an individual for its data. The lack of quantification or

[164] For a comparison of the Munsell and Ostwald systems and the ways the Ostwald system is lacking, see Bond and Nickerson (1942), p. 718.
[165] Munsell (1907 [1905]), p. 58.
[166] Titchener (1928 [1896]), p. 66.
[167] However, while the perceived rate of change is uniform along each axis, the rates of change *between* the axes do not progress at exactly the same rate: one value unit is roughly equal to two chroma units, which is roughly equal to three hue units. (Newhall (1940), p. 618).
[168] Titchener (1922 [1901]), p. 4. He writes, "A dull blue is as simple a sensation, for psychology, as a saturated blue; white is as simple a sensation as red; and black is as positive a sensation as green."
[169] Titchener (1928 [1896]), p. 48.
[170] Titchener (1928 [1896]), p. 62.
[171] Munsell (1907 [1905]), p. 68.
[172] Munsell, diaries, December 7, 1905, p. 187.

repeatability between observers made Titchener's system less scientifically appealing than Munsell's.

6. Munsell's agnosticism about color

What I call Munsell's agnosticism about color was not a preconceived principle, but developed slowly as an unstated characteristic of his working method. In fact, Munsell, those he worked with, and later researchers discussed the Munsell System in relation to the physical properties of light, pigments, and retinal stimulation. There is an extensive literature, from Munsell and others, relating Munsell color samples to these scientific explanations of color perception.[173] However, Munsell's experimental process for creating the color samples suggests that his system is better understood as self-referential. His diaries indicate how he came to this conceptual state, and shed light on how he positioned himself between the fields of art and science.

While physicists and psychologists saw the system as being useful, the diaries reveal that Munsell conceived of his work as contributing to the research on color, first in physics and then psychology, before he became "agnostic" about the colors in his system. His original inspiration from physical measurements is evident in the opening pages of his diaries, which have quotes from William Abbey's *Color Vision* and copies of Abney and Koenig's colorimetric data using spectral lights,[174] as well as many notes on the light measurements and colorimetric data of physicists such as Ogden Rood,[175] Wilhelm von Bezold,[176]and Abney.[177] Diary entries from the early 1900s reveal how he saw his system as contributing to this research: a May 1900 entry lists the primary colors in terms of their associated wavelengths, and refers to his third variable as "energy,"[178] a physical correlate of what he would later separate from his idea of chroma.

But by 1910 Munsell dropped the relation of hues to wavelength, and would increasingly collaborate with psychologists rather than physicists. An entry from 1908 illustrates Munsell's gradual transition from a physical to a psychological view of color: after the psychologist Christine Ladd-Franklin suggested several psychological texts he should study, Munsell wrote, "I question whether I could profitably attack a new and unfamiliar line of study, at my stage of *physical* research in color" (emphasis mine).[179]

This transition from working with physicists to psychologists may have led him to his self-referential system that maps the internal experience of color. A February 1909 diary entry attests to Munsell's eventual persuasion to study an internal, psychological color space: he describes his system as helping "to create a definite mental image of all color relations."[180] And an October, 1916 entry reads, "Color is in us—not outside."[181]

Yet Munsell did not completely adopt the psychologists' definition of color, their antagonistic primaries, or their method of introspection. Instead, he stopped addressing the question of what his colors "referred to." An entry from February 6, 1915, is revealing: it reads, "Bailey's desk…Present my first article "Munsell Color System: What it stands for."…It is for me to state what the system "stands for"."[182] This entry shows that he understood the pressure to tie his system to some external scale, and indicates that his silence on that matter is significant – especially since this entry comes ten years after the publication of *A Color Notation*.

6.1. A self-contained system of color

The self-referential quality of Munsell scheme is evident in the working method he outlined for making a set of samples of color in Chapter V of *A Color Notation*.[183] Although Munsell did discuss the physical correlates of color (light and pigments), these passages seem designed to make the book scientifically appealing as a broader discussion of color, and are not integral to the understanding of his color system. Though Munsell discusses prismatic color in Chapter IV, he writes that "Science" describes color this way,[184] and then moves on. Throughout the rest of the text, Munsell almost exclusively refers to colors using his own system's terminology – by their Hue, Value/Chroma – and remains uncommitted as to what these colors "are." Once the hues are painted on the Maxwell disk papers and the value scale set with the photometer, the rest of the procedure only refers to these established variables.

The chroma scale, similarly, was not a measure of how much white light is in the color or reflected from the pigment, but instead was created by comparing colors already within the system. That this was unusual to a scientist of the time is evident in a diary note from December 24, 1901, which reads that Dr. Bowditch of Harvard Medical School "Says scientists talk of decrease of saturation by adding white light – but my notion of loss of chroma without change of value or hue is a new one to him and very interesting."[185]

The self-referential nature of Munsell's working method is subtle, but because he was not constrained by the physical properties of the wavelengths of light or the limitations of pigments, he could compare the colors of his system to themselves and incrementally alter one variable at a time, creating perceptually uniform changes. The result ended up accurately mapping the internal *experience* of color.

6.2. Munsell's position as an artist/scientist

Rather than try to classify Munsell as a scientific "insider" or "outsider," his work may be seen as an example of the mutual influence of art and science.[186] Though Munsell was thoroughly steeped in the scientific world, he ultimately gained respect instead through his experience as a trained artist. The authority Munsell commanded was not as an "artist" in the Romantic sense of the word, but as an "artist" who is a "trained expert"[187] along Daston and Galison's lines of the epistemology of "trained judgment."[188] His accumulation of experience viewing and reproducing colors gave him more authority when judging colors by what may have seemed to be unconscious criteria of the eye.[189]

[173] Munsell's diaries are replete with notes about the physics of light and the physiology of the eye. For later work with Munsell samples see, for example, Gibson and Nickerson (1940), which also cites many other studies.
[174] Munsell diaries. On p. 11 he quotes from Abbey's *Color Vision* and on pp. 12 and 32 seems to have copied out some color-matching graphs. Also see Kuehni (2002), p. 25.
[175] See, for example, what appear to be spectral sensitivity curves Munsell copied into his diaries, possibly from Abbey's *Color Vision*. Munsell diaries, pp. 9–12, and Munsell diaries, pp. 1, 7, 7a, 22, and 26.
[176] Munsell diaries, p. 8.
[177] Munsell diaries, pp. 9, 11, and 12.
[178] Munsell diaries, p. 28.
[179] Munsell diaries, Sept 24, 1908, p. 237.
[180] Munsell diaries, p. 247.
[181] Munsell diaries, p. 421.
[182] Munsell diaries, pp. 395–6.
[183] Munsell (1907 [1905]), pp. 66–76.
[184] Munsell (1907 [1905]), pp. 21–3.
[185] Munsell diaries, p. 84.
[186] This is similar to the ideas about how artists/artisans interacted with natural philosophy in Smith's (2004) work, *The Body of the Artisan*.
[187] Daston and Galison (2007), p. 359.
[188] Daston and Galison (2007), chapter VI.
[189] Daston and Galison (2007), p. 314.

Despite his involvement in the scientific community, Munsell did not define himself as a scientist, as an entry from December 21, 1912 reveals: he writes that Dr. Henderson "says the next thing is a scientific statement of my contribution to science and he will try to arrange to make it with me (as I say it is beyond me) – using my diaries."[190] That his status as a painter was valuable at this moment is evidenced by a comment he recorded from Worthington Ford: "Thinks I have been drawn into this inquiry as an artist, - not as a manufacturer – and that this professional view of color will arouse interest and respect among scientists."[191]

Munsell had expertise as a trained artist that interested scientists and non-scientists alike. The diaries note several lectures Munsell gave on a topic he previously discussed with Prof. Yerkes: "color in masterpieces and their probable balance."[192] In December of 1910 he gave a talk on Rembrandt at the Museum of Fine Arts,[193] and in November of 1911 he gave a lecture titled "The Relations of Light, Color and Art" about how his color sphere could be used in "gauging the colors of paintings and decorations."[194] Munsell's artistic authority was also valued in the scientific world. An April 8, 1904 entry quotes the physicist Amos Dolbear as saying, during a visit in which he viewed a portrait Munsell was painting, that Munsell's color system "may furnish a track across what is now a desert between practical and scientific color work."[195] This shows Dolbear's interest in using the experience of a painter as a springboard for further work on color.

7. Conclusion

Munsell's color system was the first to accurately and quantitatively describe the phenomenological experience of color. His key innovations were to chart an irregularly shaped psychological color space and to create perceptually uniform, independently functioning axes of the variables of color.

By comparing his working method and resulting system with those of three contemporary scientists – Wilhelm Ostwald, Ogden Rood, and Edward Titchener – I have shown how implicit assumptions about the nature of color could have subtly prevented scientists from reaching the same conclusions as Munsell. Although Munsell was thoroughly familiar with the contemporary scientific views of color, he came to the unique features of his system by disregarding the question of what "color" is; by putting aside the physical correlates of color in spectral light, the action of the sensory nerves, and contemporary psychological practices of introspection. Instead, Munsell's system provided a practical solution to the particular problems of color in art and the different scientific disciplines.

Munsell's Academic art training inspired him to provide a system that could be broken down into easily mastered pieces, while the objective, notational structure of the system answered the problems of accurately matching and recording artistic color. These characteristics also proved useful to psychologists, who needed a standardized representation of the human psychological experience of color, while his methodology was quantitative and objective enough to be acceptable to physicists. Even though the Munsell System is not a universal standard of color today, it laid the groundwork for further progress in each field by providing physical color samples that could be tested and refined, establishing that color perception can be described by three independent variables, and accurately mapping the irregularities of human color perception.

Acknowledgments

I am indebted to Robert J. Richards and Jennifer Karlin for their help with this paper, and to the two anonymous reviewers for their comments.

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[190] Munsell diaries, p. 355.
[191] Munsell diaries, June 19, p. 71.
[192] Munsell diaries, Oct 10, 1910, p. 277.
[193] Munsell diaries, p. 283.
[194] Munsell diaries, Nov. 17, 1911, p. 300.
[195] Munsell diaries, p. 144.

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