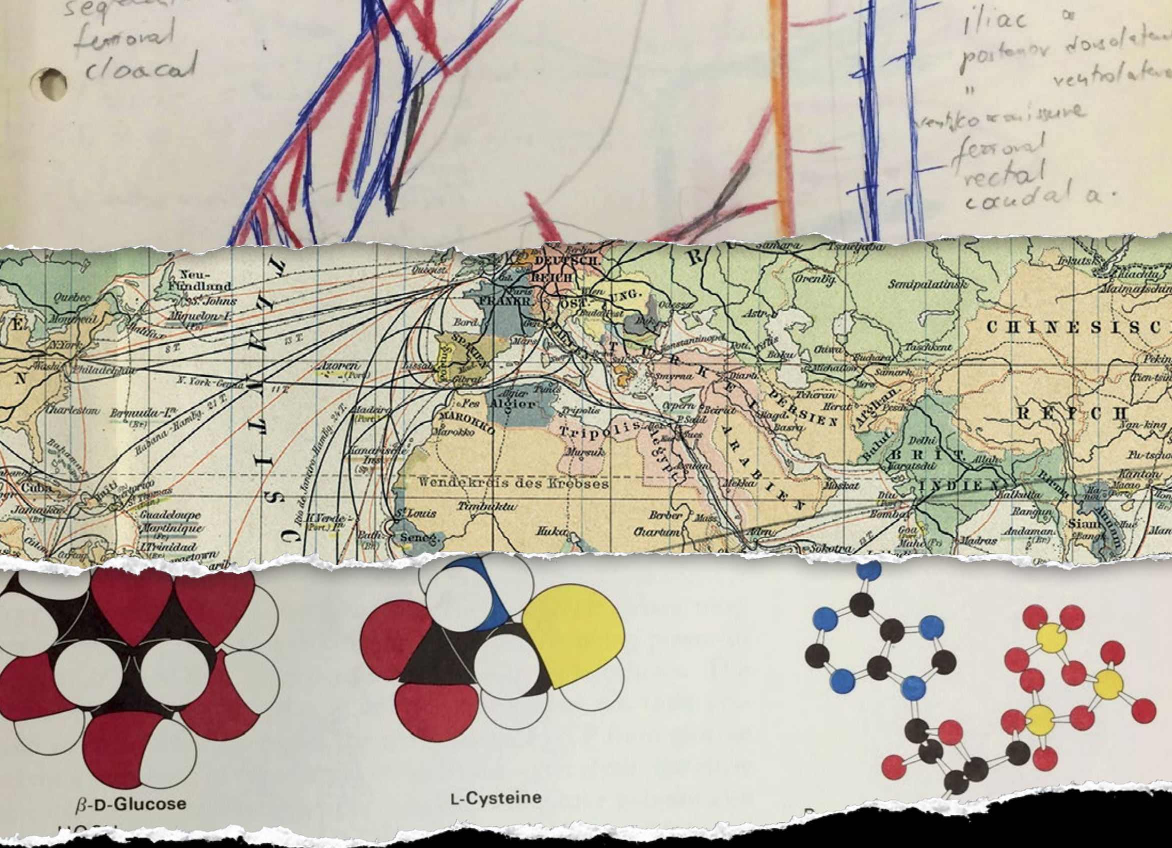
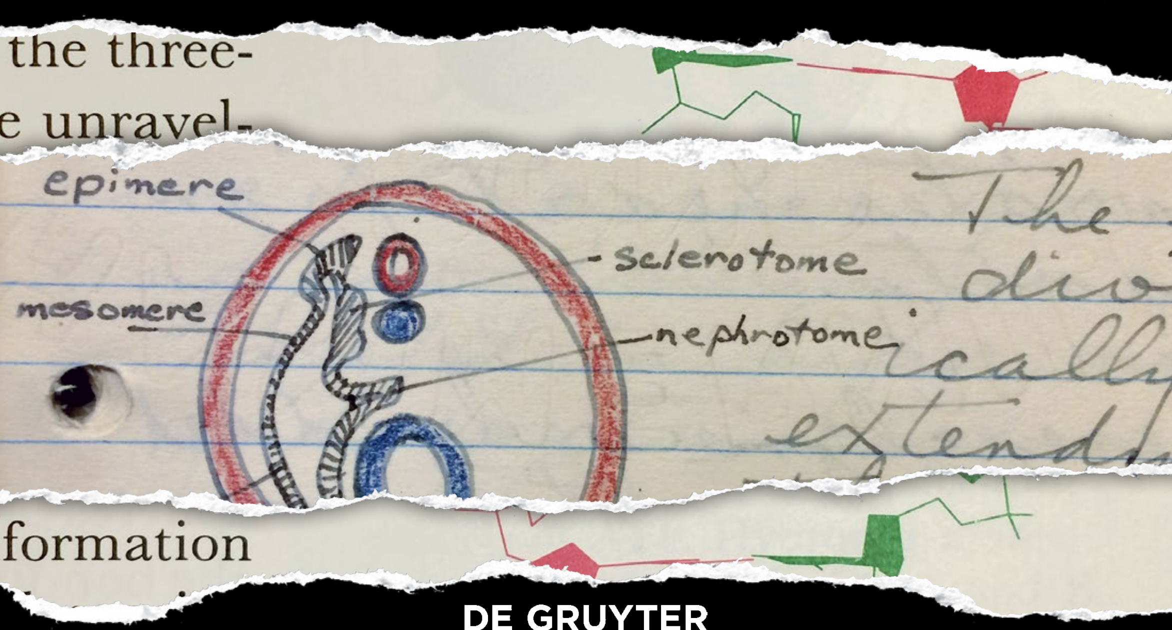


Bettina Bock von Wülfingen (Ed.)

SCIENCE IN COLOR

Visualizing Achromatic Knowledge



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MEANINGFUL COLORS IN THE SCIENCES

Editorial

Why color?

Three events will illustrate what motivated this volume: At a conference on the Meaning of Color in Berlin in July 2018, a researcher talked about her ethnographic field work in geobiology during a trip to a tropic island. What might have sounded like a fancy holiday destination was in fact a hostile environment to most living things, seeing that it provided no fresh water or shelter from sun. She was there to observe and interact with geobiologists who study the microbial communities that build dense layers in swamps and exist in only a few regions of the world. She watched the geobiologists measure the density of layers and record colors. They also took photographs as documentary evidence. The colors of the layers were key to age and composition. During the conference on the Meaning of Color in Berlin, someone in the audience asked, "So what kind of Munsell-like color scale do they [the geobiologists] use to give the colors their correct and specific names?" To which the ethnographer replied, "There is no such thing. That is tacit knowledge." Nobody said a word. The Finnish expert on the color green, who had asked the question, looked incredulous. The digital media researcher next to him raised his hand: "So with what kind of standardized camera technology do they take their photos?" The ethnographer: "Um, with their own smartphones, mostly."

The second example concerns diagrams. In an interview, the Harvard professor of Biochemistry Alain Viel was asked about his textbook in the making: "How do you decide which kind of blue to choose for these acid-endings in your diagram?" Viel: "Oh, I *like* this blue!".[1] he answered pointing at the blue arrows in a diagram on his monitor. Similarly, in an interview, biochemist Gerhard Michal, author of the most widespread biochemical map *Biochemical Pathways*, first produced in 1965, told me about the choice of colors in his diagram: "I asked the printer to show me the blues he most liked and of these we picked the nicest blue."[2]

The third case is from the realm of medicine. Aldo Badano, one of the authors in this volume, is a researcher at the Food and Drug Administration in the United States involved in evaluating the safety of monitors used in clinical contexts. At a conference on color in Berlin in 2016, he presented one of the first studies to investigate the strongly held belief within the medical field that color in images

1 Alain Viel: *Interview*, transcript: Cambridge, PA, 2018.
2 Gerhard Michal: *Interview*, transcript: Munich, 2018.

makes them easier to read. There had been no study thus far to verify the diagnostic performance of medical practitioners including cardiologists and radiologists in relation to the color scale of the monitor used.

The reason why, in the first case, the expert on green and the expert on digital visual technology were struck by the procedure used during the expedition in geobiology was the absence of color standardization. On the one hand, we know from the history of science that starting in the seventeenth and extending well into the twentieth century early scientists, particularly in fields such as botany, zoology, geology and meteorology, used color cards for standardization, which helped to measure, transfer and communicate color impressions. Archaeologist Alexander Nagel, also an author in this volume, propagates the use of Munsell's color charts (developed at the beginning of the twentieth century by the painter and art professor),[3] often used to describe soil in geology and archaeology, to describe paintings on antique artifacts. On the other hand, different digital (and analog) camera technologies and screens capture, store and display colors differently. They achieve different results as regards to hue, saturation and value or lightness – terms which computer graphics researchers since the 1970s have used to represent perceptual color models such as Munsell's.[4]

The diagrams mentioned in the second example were used in the biochemistry textbooks and wall charts sold until the end of the twentieth century to teachers and students in disciplines ranging from chemistry to medicine. Today, they have been replaced by online versions with similar symbolic and aesthetic features. We learn from the literature that their use in an educational context raises perceptual, pedagogic and psychological questions.[5] What we do not learn from the literature

3 Albert H. Munsell: *Atlas of the Munsell Color System,* Boston: Wadsworth, Howland & Co., Inc, 1915; Albert H. Munsell: *A Color Notation,* Boston: G. H. Ellis Co, 1905.

4 Edward R. Landa, Mark D. Fairchild: Charting Color from the Eye of the Beholder. In: *American Scientist,* 93 (5), 2005, pp. 436–443; Steven K. Shevell: *The Science of Color,* Oxford: Elsevier Science & Technology, 2003; Michael W. Schwarz, William B. Cowan, John C. Beatty: An Experimental Comparison of RGB, YIQ, LAB, HSV, and Opponent Color Models. In: *ACM Transactions on Graphics,* 6 (2), 1987, pp. 123–158; John Kender: *Saturation, Hue and Normalized Color: Calculation, Digitization Effects, and Use*, Pittsburgh: Carnegie Mellon University, Computer Science Department, 1976.

5 Marissa Harle, Marcy Towns: A Review of Spatial Ability Literature, Its Connection to Chemistry, and Implications for Instruction. In: *Journal of Chemical Education,* 88 (3), 2010, pp. 351–360; David Kaiser: *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics*, Chicago: University of Chicago Press, 2009; Michelle Patrick Cook: Visual Representations in Science Education: The Influence of Prior Knowledge and Cognitive Load Theory on Instructional Design Principles. In: *Science Education,* 90 (6), 2006, pp. 1073–1091; Hsin-Kai Wu, Priti Shah: Exploring Visuospatial Thinking in Chemistry Learning. In: *Science Education,* 88 (3), 2004, pp. 465–492; Jorge Trindade, Carlos Fiolhais, Leandro Almeida: Science Learning in Virtual Environments: A Descriptive Study. In: *British Journal of Educational Technology,* 33 (4), 2002, pp. 471–488; James H. Mathewson: Visual-Spatial Thinking: An Aspect of Science Overlooked by Educators. In: *Science Education*, 83 (1), 1999, pp. 33–54.

is information on the color choices in these diagrams, especially regarding intercultural contexts. This also concerns possible intercultural differences in reading the different colors in different maps.

In the last case, the results of the 2015 study by Badano et al. on monochrome images on monitors (which are in grayscale mode) versus polychrome monitors in the medical context showed that people trained on monochrome monitors had difficulty interpreting polychrome images and vice versa. This, they were able to show, influences performance in the detection and demarcation of lesions by the study participants. Yet, there was no knowledge of the relevance of color for the physicians' performance in the respective institutions.

To conclude, on the one hand, we have reasons to believe that most natural scientists encounter color and need to employ color in their empirical, technical and educational work and would benefit from systematic studies of the (history) of the use of color in images. As detailed below, on the other hand, the status of research in the social sciences relating to science and technology, as well as in history and philosophy of science and technology, seems to reflect the generally low awareness of the relevance of color in the sciences and technology. Where theoretical reflections on scientific images have been undertaken, the history of science has been the main field producing individual studies on color. We can divide these studies into the history of the ontology of color, which is most often the history of physics,[6] studies on the history of color charts for standardization in the sciences and technology,[7] studies that analyze the history of color as material substance,[8] and those that relate mimetic color use to reproduce the living aspect of zoological or botanical objects,[9] as well as the mimetic use of color in other disciplines such as

6 E. g. Klaus Hentschel: Verengte Sichtweise. Folgen der Newtonschen Optik für die Farbwahrnehmung bis ins 19. Jahrhundert. In: *Farbstrategien*. Bildwelten des Wissens, 4.1, Berlin, Boston: de Gruyter, 2006; and in M. Bushart, Friedrich Steinle: *Colour Histories, Science, Art, and Technology in the 17th and 18th Centuries,* Berlin, Boston: de Gruyter, 2015; T. Baker, S. Dupré, S. Kusukawa, K. Leonhard: *Early Modern Color Worlds*. In: *Early Science and Medicine, 2*0 (4-6), 2015, pp. 289–591.

7 See e. g. André Karliczek: Zur Herausbildung von Farbstandards in den frühen Wissenschaften. In: *Ferrum,* 90 (Nachrichtenblatt der Eisenbibliothek), 2018, pp. 36–49; A. Temkin, B. Fer, M. Ho: *Color Chart: Reinventing Color, 1950 to Today,* The Museum of Modern Art, 2008; Rolf Kuehni, Andreas Schwarz: *Color ordered: a survey of color systems from antiquity to the present*. Oxford: Oxford University Press, 2008.

8 See e. g. Jan Altmann: Färbung, Farbgestaltung und früher Farbdruck am Ende der Naturgeschichte. In: Farbstrategien (s. fn. 6), pp. 69–77; Alexandre Métraux: Farbstoffchemie, Farbexperimente und die französische Malerei. In: Farbstrategien (s. fn. 6), pp. 61–68.

9 As in Kärin Nickelsen: The Challenge of Colour: Eighteenth-Century Botanists and the Hand-colouring of Illustrations. In: *Annals of Science,* 63 (1), 2006, pp. 3–23.

geology, meteorology or medicine.[10] Appreciating all these groundbreaking works on color in science, authors in this volume deal with the *meaning* of color: what does it mean in specific fields of medicine, philosophy or to a specific scientific discipline to use or not to use color? And to focus on the other meaning of meaning: what do specific colors mean in specific (scientific) contexts? And how do they come to acquire these meanings?

How the book is structured

The volume is divided in two parts in accordance with the two meanings of meaning of color:

The first half of the articles deals with "meaning" in the sense of relevance or irrelevance, with the simultaneous use and neglect of color in the sciences, as something generally disapproved or something useful – as an object to reflect on in the sciences and medicine themselves. Some of them take David Batchelor's claim of a "Western chromophobia"[11] from antiquity to modernity as a point of departure, mainly to contradict the coarseness of this claim and to show the complex contradictions of color use and neglect in different countries, times and contexts. Still, reading all the contributions together, it did seem in our discussions that in specific historic contexts and moments, in times of backlash after phases of more emancipatory democratic social change, chromophobia became part of racialized and gendered discourses that re-aligned politics, sciences and arts. This is at least what we suggest as a field of research that requires further study.

This first group of articles begins with the contribution by Aldo Badano, whose article shows that not to reflect on the use of color in the sciences and medicine may become in practice, dramatically enough, a question of life and death. Ulrike Boskamp, Alexander Nagel and Esther Ramharter follow with problematizations and contextualizations of Batchelor's claim. They distinguish different historic moments, disciplines and uses of color. Michael Friedman demonstrates a field of chromophilia: the use of color on mathematical models. We close the first half with Ricardo Cedeño Montaña's study, which focuses on the history of studies on the visual apparatus and color perception. It is the bridge to the second group of

10 See e.g. in Baker et al. (s. fn. 6), pp. 289–591; Klaus Hentschel: *Visual Cultures in Science and Technology: A Comparative History*, Oxford: Oxford University Press, 2014; Farbstrategien (s. fn. 6) ; on different roles of colour in relation to form in the scientific image see Horst Bredekamp, Vera Dünkel, Birgit Schneider (eds.): The technical image: a history of styles in scientific imagery. Chicago: University of Chicago Press, 2019..

11 David Batchelor: *Chromophobia,* London: Reaktion books, 2000.

articles which focus on the meaning of color in the sense of color being a symbol of something else, and on specific colors and their connotations – i. e., their respective cultural meaning or symbolism. Michael Rossi makes a start with the history of knowledge generation on the perception of green. Ian Lawson shows how the concept of primary colors with some delay led to the acceptance of orange in the color terminology in Europe. His contribution is followed by four articles which all study the meaning of color in various sorts of maps: Daniel Baum on color maps as such; Jana Moser and Philipp Meyer on geographic maps; Jean-François Moreau, Jean-Michel Correas and Raffaele Pisano on the medical imaging technique in Color Doppler Ultrasound (which are topographical maps, too), and finally, Bettina Bock von Wülfingen on metabolic maps. Dominique Grisard closes with the history of psychological studies, which result in naturalizing the gendered conception of pink.

Shared problems

The idea of claiming specific meanings and connotations of color as natural and universal is a theme that runs through all the texts. They demonstrate the opposite: connotations of color change synchronically and diachronically; they are bound into the contexts they appear in.

"The meaning of color" in almost all the contributions signifies cultural connotation but often also primarily refers to questions about values – social, cultural, sometimes supposed technical values that turn out to be cultural values shaping color use (e. g., in Ricardo Cedeño Montaña's case, there are contingent reasons why color use is understood as advantageous in some cases or nonsense in others). Standardization and the lack thereof and the historic moment in which it appeared (if it indeed did so) as well as the timescale in the shift of values reappear as problems in most of the contributions. The articles in this volume deal with a broad range of historic and modern color uses and types. While those articles dealing with late modern forms of visualizations (mostly on screens) work with the opposition of true versus pseudo color, for others the distinction of mimetic and symbolic color use is in the foreground.

This volume makes use of the existing rich studies on the history of color in science and tries to pave the way for more studies on the meaning of color. As previously stated, further work on historically contingent moments of chromophobia and chromophilia would be worthwhile. Another suggestion for further research resulting from our discussion is global history and transculturalism in studies on color use. Almost all articles in our compilation analyze the uses of color in scientific contexts of – to put it bluntly – the global North-West. Alexander Nagel's study is on descriptions of color use in architecture in the Near East but focuses on its reception by German and English scientists; Bettina Bock von Wülfingen's study compares German and Japanese metabolic maps – still, we are far from provincializing Europe and the United States. Nevertheless, this volume's subject raises questions and issues that can be investigated in and across other contexts, and presents a first harvest of results concerning the way scientific cultures use, adopt and think about (or rather choose to ignore) colors.

Bettina Bock von Wülfingen

COLOR AND ITS MEANING FOR THE SCIENCES

Aldo Badano

Color in Medical Images

Despite its widespread use in the interpretation of medical images, color is handled primarily in an ad-hoc manner due to the lack of standard approaches for optimal visualization. The variability introduced by varying color treatments leads to reproducibility concerns in quantitative image evaluation and low inter-observer agreement possibly leading to inconsistent diagnostic decisions with a negative impact on patient treatment and prognosis. Medical imaging techniques that rely on pseudo-color presentation include perfusion techniques, diffusion-weighted magnetic resonance and nuclear imaging. Other modalities use absolute color transfer including medical photography and the emerging field of digital whole-slide imaging and digital pathology. Some have suggested that specific color scales for non-contrast computed tomography of arterial function improve diagnostic confidence, diagnostic accuracy and inter-observer agreement with respect to a grayscale presentation. Moreover, recent research using synthetic and patient images in laboratory and clinical settings indicates that benefits from using color scales is modality dependent and is affected by reader training and by variations in the training and interpretation practices across geographical regions and across schools and health institutions. What is the reason color is used in medical imaging? Is it to improve the performance of the clinician or rather to visualize data that would otherwise be imperceptible? In either scenario, one can also ask if it is at all possible to define meaning within the context of a medical and engineering framework. In this chapter, we discuss current understandings and utilization of color in medical imaging applications and present a perspective for the abovementioned questions from the viewpoint of the utility of color images for the advancement of human well-being.

Epistemological landscape

The meaning of color in medical imaging can be analyzed within the context of the scientific and technical advancements in the field, the processes that lead to their introduction into clinical practice and the learning aspects that are inherent with any new technology. For more than a century, radiological images have been interpreted using grayscale or monochromatic representations primarily driven by traditional single-phosphor radiographic film media. The visualization of images acquired and displayed using radiographic film were consistent with the measurement of the attenuation of x-rays through body parts revealing interior details

Ulrike Boskamp

Color as the Other?

Absence and Reappearance of Chromophobia in Eighteenth-Century France

> *"I feel the color in my cheeks rising again.*
> *I must be the color of The Communist Manifesto."*[1]

In E. L. James's popular novel *Fifty Shades of Grey* (2012), this is the physical reaction that Anastasia Steele, the female protagonist, shows at her second meeting with Christian Grey. In accordance with his colorless name, he features gray eyes, gray suits, white office furniture. The book's original title clearly references this "male" side of the story (FIG. 1).

Grey embodies what David Batchelor has very appropriately named "chromophobia." Handsome, rich, lonely, neurotically self-controlled, he wishes to control his surroundings, derives sexual pleasure from dominance over his partner, and he never blushes. In the novel, color is reserved for the female's skin, which turns various shades of red caused by the male, either when she blushes or when she is beaten. The book's highly conventional setup of male domination and female subordination, an unambiguous hierarchy that is sexually played out in soft porn, uses and reconfirms a clear binarism of gender with great public success at a historical moment in which this binarism is being very seriously contested. It includes what the art historian Abigail Solomon-Godeau, referring to images, has called a "staging of the relationships of dominance and submission, authority and subordination, deeply inscribed into the structures of patriarchy and phallogocentrism."[2] Color and its marked absence play roles in this staging by transmitting their semantics to the subjects they are assigned to.

Batchelor has dedicated his book *Chromophobia* to this binary, hierarchic relationship. He proposes that the case of color and its subordination "is bound up with the fate of Western culture,"[3] and accordingly presents the subjugation of a triad of color, the female and a conglomerate of matter, body and nature under its

1 E. L. James: *Fifty Shades of Grey*, London: Arrow Books, 2012, p. 28. I thank Annette Kranen for her critical reading of this article.

2 Abigail Solomon-Godeau: Ist Endymion schwul? Spannungsgeladene Fragen zwischen Feminismus, Gay und Queer Studies. In: Mechthild Fend, Marianne Koos (eds.): *Männlichkeit im Blick. Visuelle Inszenierungen in der Kunst seit der frühen Neuzeit*, Cologne: Böhlau, 2004, p. 34.

3 David Batchelor, *Chromophobia*, London: Reaktion Books, 2000, p. 22.

Alexander Nagel

Research on Color Matters: Towards a Modern Archaeology of Ancient Polychromies

The current excitement for digital polychrome reconstructions of ancient monuments corresponds to new energies and investments made in advanced image technologies and the development of innovative computer graphic tools in the twenty-first century. Until about a generation ago, enthusiastic explorers used traditional tools to construct how they believed the polychrome past of the ancient world looked like. Occasionally, these physical constructions generated harsh debate, yet the reasons for the debates were complex and in general not limited to what the British art historian David Batchelor has defined as Chromophobia.[1] Physical constructions such as those shown in the contemporary traveling exhibition Bunte Götter are still important as we practice thinking more about the complex technologies of paint application and the materials used. Though academics understand that pre-modern sculptures and monuments were brightly painted, every new generation will need to be educated about this one aspect of the past. The goal of this article is to illuminate and contextualize some aspects of the complex history of research, documentation and debate on past polychromies, with particular reference to monuments excavated in Egypt, Persia and Mesopotamia. As my article will show, documenting and defending color has never been an easy task. Beginning with a brief introduction on systems of documenting color in archaeological ceramics, I will introduce a cast of key players and individuals involved in the documentation, "measuring" and translation of hues and colors from the field to the museum and beyond, all invested in the early business of reconstructing sculptural painting (polychromies) in the nineteenth century. I will also discuss ways how these participants' observations and documentation were acknowledged and distributed in European salons and media.[2]

1 David Batchelor, *Chromophobia,* London: Reaktion Books, 2000.

2 I confess that this is a very Western biased approach. I mainly question how European scientists thought and wrote about ancient polychromies in the Middle East. I recognize the important new contributions made on antiquarians researching colors in the Islamic world in recent years: Sheila Blair, Jonathan Bloom (eds.): *And Diverse are their Hues. Color in Islamic Art and Culture*, New Haven; CT, and London: Yale University Press, 2011.

Esther Ramharter

Do Signs Make Logic Colored?

Tendencies Around 1900 and Earlier

Color plays a role in philosophy and in logic as well: What meaning does color have for logic, and has this changed over time? David Batchelor, in his book Chromophobia,[1] diagnoses a repression of color in Western culture because color has been considered a permanent threat, in particular to rationality. With respect to the relation of the two dichotomies colors/black-and-white and male/female, Ulrike Boskamp has developed a more differentiated view in her contribution to this collection. Does logic have its own privileged relationship with color, or is this connection merely a special case of the (perhaps hostile) relationship between color and rationality? The main emphasis of this paper, however, is on the role that (written) signs play in the relation between color and logic.

Rationality and logic

There has been a close connection between rationality and logic since antiquity, with many parallel discussions surrounding this subject: scholars have asked whether there is one universal rationality or many rationalities, and monism versus pluralism has appeared as a topic of ongoing debates in logic. Authors queried whether the field of psychology instead of philosophy is the appropriate place for both studies of rationality and of logic. The respective possibility to include contradictions is a matter that has bothered very different philosophers. And although these issues have – at least partially – been discussed independently for the two different concepts, rationality and logic, the connection between them is ultimately inescapable.

According to perhaps the most commonly held conception of the relationship between logic and rationality, logic is viewed as a part of rationality. One early example of the development of such a conception comes from Aristotle, who held that logic, i. e., syllogistics or dialectic, is how we reason correctly. But since reasoning requires a starting point, something must be responsible for the beginning of this process. This is the intellect (νοῦς/nous).[2] Hence, intellect and reasoning combine to make what one might term “rationality.” What this understanding of rationality

1 David Batchelor: *Chromophobia*, London: Reaction Books, 2000.

2 See Aristotle: *Analytica Posteriora* 100 b, 5–17.

Ricardo Cedeño Montaña

Encoding Color: Between Perception and Signal

Input

Encoding schemes for producing, storing, and transmitting color information in electronic media are based on the additive mixture of red, green, and blue lights, a three-color principle that originated in nineteenth-century physiological studies of vision. During the twentieth century this principle was first standardized and then implemented in several technical media. Similar to many other aspects of media technologies, over the past century there has been a standardizing trend to order, regulate and stabilize the production of color sensations with electronic media. The standardization of color has been an essential part for the creation of ever more precise and predictable sensors, displays and encoding schemes.

Two images open this chapter (FIG. 1). Both are magnifications of the input and output hardware of electronic visual systems where the three-color principle has been implemented. Both are standard pieces used in consumer imaging devices. The micrograph on the left corresponds to the charge-coupled device image sensor installed in a common webcam. The image on the right is a macro picture of an in-plane-switching liquid-crystal display. The input is a rectangular grid of circular photodiodes and the output is an arrangement of chevron-patterned electrodes. There are only red, green, and blue elements, but their distributions differ. Half of the photodiodes on the image sensor are green, whereas on the display the colors of the electrodes are evenly distributed.

The nature of color has been studied in history, science and philosophy of color. However, it is only with the recent material turn that focuses on the media technologies as the concrete link between science, industry and culture that the question of color in electronic media has been addressed by media history.[1] This chapter describes how a certain interplay of ideas, instruments, blueprints and specifications gave birth to the trichromatic theory and its implementation in electronic media. This media history focuses on the works and agreements among a network of scientists and technicians that after explaining this human sensation as the mixture of three primary stimuli, fostered a series of technical developments to homogenize the color sensations produced by electronic media. From sensing device to transmission channel, electronic color is a media operation that exploits

1 Susan Murray: *Bright Signals: A History of Color Television*, Durham: Duke University Press, 2018.

MEANINGFUL COLORS IN THE SCIENCES

Michael Rossi

Green Is Refreshing: Techniques, Technologies and Epistemologies of Nineteenth-Century Color Therapies

In an early lecture of 1860, philosopher Charles Sanders Peirce reached for a seemingly obscure example in order to explain how things became perceivable to conscious beings. It was distinctness or distinction, Peirce told his audience, that rendered things sensible. In order to be perceived as a thing (rather than nothing, or everything), an entity – a chemical, an object, a person, a thought, an idea, a sensation – had to be distinguishable from that which it was not. By way of example, Peirce directed his audience's attention to an ostensibly elementary sense perception – that of color. "There is a gentleman in England," he wrote, "who has shown by an ingenious research that everything appears green to him. Green however, is not a refreshing color to him, because it is undistinguished."[1]

On first pass, the point seems conventional, and the example arbitrary. To see something as a thing itself, it must appear distinct from other things. If all things appear to be green (for instance), then green has no meaning as a descriptor – it is indistinct because it describes everything indiscriminately. As with green, so too with all colors, and, indeed, all things in the world. In order to be identifiable as something, a thing (a color, an object, an idea) must be not-other-things.

On closer reflection, however, one is struck by the strangely specific wording Peirce uses. It is not simply that green is *recognizable* when distinguished from other colors. Rather, green is *refreshing* – in its distinctness, it has effects upon the human body, and these effects are absent when green is indistinct. It's a striking notion, made all the more striking by the offhandedness with which Peirce offers it. Peirce assumes that his audience would be familiar with the fact that green is "refreshing." Further still, with his mention of the "ingenious research" of "a gentleman in England," he signals his familiarity with scientific work on color perception: the "gentleman" is John Dalton, a celebrated chemist famous for writing about his own color blindness.[2]

1 Charles Sanders Peirce: Views of Chemistry, Sketched for Young Ladies. In: Max Harold Fisch, Peirce Edition Project (eds.): *Writings of Charles S. Peirce: A Chronological Edition,* Vol. 1, Bloomington: Indiana University Press, 1982, p. 50.

2 Peirce oversimplified the matter. Dalton did not write that everything appeared green to him. Rather, he had difficulty distinguishing reds, purples, oranges and pinks from different shades of green.

Ian Lawson

Pigments, Natural History and Primary Qualities: How Orange Became a Color

A physiological table of colors

In 1686, the naturalist, watercolorist, translator and philosopher Richard Waller († 1715) published a "Physiological Table of Colors."[1] It was an innovative moment in the history of color printing. He had designed a set of glass pipes stopped with spring-loaded plugs, to be filled with colors. When the plugs were moved aside "the color came down so as to make convenient round spots on the paper" (FIG. 1).[2] As long as the weights of the pigments in the pipes were kept constant, Waller reasoned, different versions of the table would be identical. Each round spot was labelled with Latin, Greek, French and English names, and the table would thus stabilize nomenclature for these specific shades of color. A naturalist could describe a young plant's "sea green" or "*vitreus*" leaves and a reader with the same catalogue in front of them would understand the object, Waller hoped, "with less ambiguity, I think, than is usual: A Standard of colors being yet a thing wanting in Philosophy."[3]

This table lies at the intersection of natural history, linguistics, painting and philosophy, and represents Waller's particular way of thinking about color. In this paper I draw connections between this table and contemporary seventeenth-century ideas about primary colors. I argue that Waller's table visualizes color mixing in a way that gives us an insight into the history of this idea, and of one secondary color particularly: orange. Orange is conspicuous by its absence in Waller's table, and in other seventeenth-century color theories. Indeed, originally referring to the fruit, the emergence of the word "orange" as a color term has been dated to roughly this time,

1 Richard Waller: A Catalogue of Simple and Mixt Colours, with a Specimen of Each Color Prefixt to Its Proper Name. In: *Philosophical Transactions*, 16, 1686–1692, pp. 24–32. For more on the history of the table and its contents, see Sachiko Kusukawa: Richard Waller's Table of Colors (1686). In: Magdalena Bushart, Friedrich Steinle (eds.): *Color Histories, Science, Art, and Technology in the 17th and 18th Centuries*, Berlin: De Gruyter, 2015, pp. 3–24.

2 Thomas Birch: *The History of the Royal Society of London for Improving of Natural Knowledge*, vol. 4, London: A. Millar, 1756–1757, p. 480. As far as I know, there are three surviving colored copies, one each in the Trinity College and Cambridge University libraries in Cambridge, England, and one in the Smithsonian Museum, USA.

3 Waller (s. fn. 1), p. 25. The idea of using color reference chips in scientific fieldwork is familiar to us now through the Munsell Color System. Waller belongs to its ancestors. For Munsell see e. g. Rolf G. Kuehni: The Early Development of the Munsell System. In: *Color Research and Application*, 27, 2002, pp. 20–27.

Daniel Baum

An Evaluation of Color Maps for Visual Data Exploration

Introduction

Color is often used in data visualization as an additional cue to support the understanding of the data being visualized. However, care needs to be taken when applying color since it influences our visual perception enormously. Over the past sixty years, the use of color in data visualization – a subfield of computer science – has been studied in great detail. This has led to many generally accepted rules for the use of color. An important aspect when using color is the task to be carried out or the goal to be achieved. A different task may lead to different requirements for the usage of color. When feature detection is the main goal, for example, other color schemes may be more appropriate than those that would be beneficial for an overview of the data. The usability of color is further restricted when three-dimensional (3D) objects are the target of the visualization. In this case, for example, luminance should be avoided to represent differences in the data that is visualized on the surface of the 3D object because the luminance parameter is already required to better accentuate the shape of the object (see the last example in this article). Hence, in order to use color most effectively, many considerations need to be made. In this article, we focus on visualizing continuous scalar-valued data. Such data is usually depicted with the help of color maps that assign to each scalar value a single color. The term "color map" originally referred to a color lookup table that was used in computer graphics to map scalar values to a specific color to be depicted on the computer screen.[1] While this article focusses on continuous color maps, different aspects of color for data visualization are considered in other articles of this volume. Also note that the term "color map" might be used differently throughout this volume (see, for example, the article by Jana Moser and Philipp Meyer, and the article by Bettina Bock von Wülfingen).

Let us consider a first example. The data depicted in FIGURE 1 is a three-dimensional (3D) image of a marine sediment core containing coral and sea shell fragments. This 3D image was acquired using computed tomography (CT). The 2D visualizations depicted in FIGURE 1 show the same cross-section of this CT image.

1 Kenneth R. Sloan Jr., Christopher M. Brown: Color Map Techniques. In: *Computer Graphics and Image Processing*, 10, 1979, pp. 297–317; Garland Stern: SoftCel – An application of raster scan graphics to conventional cel animation. In: *ACM SIGGRAPH Computer Graphics*, 13, 1979.

Jana Moser, Philipp Meyer

The Use of Color in Geographic Maps[1]

In geographic mapmaking, i. e., regarding maps that rely on geographic space and display a specific space-related content, color is only one minor but very effective aspect to design a map and its content. Today's mapmakers – especially in Europe – still rely on the development of Bertin's graphical variables of the 1960s (FIG. 1), with additions by MacEachren in the 1990s.[2] Regarding color usage in maps, it is important to distinguish between hue, value and luminance[3] as well as to consider the output medium for a map to use the appropriate color system (RGB, CMYK).[4] It is possible to produce maps in grayscale, i. e., without color. In fact, if not handcolored afterwards, almost every printed map was colorless until the end of the eighteenth century for printing reasons alone. Today, grayscale maps are mostly used for economic reasons. On the other hand, monochrome black-and-white mapping was also intentionally used, especially in propaganda maps in the first half of the twentieth century.[5]

Color is nonetheless one of the most impressive map features. Color can be associative, selective or ordering. It can support the reader in obtaining information at first sight. Color can raise readability and efficiency in map interpretation. It is able to bring order and clarity into the confusion of lines and names. Color emphasizes or summarizes, distinguishes, highlights or balances specific spatial areas or given content. In addition, one of the main arguments for using color in maps is aesthetics, whereby colorizing a map means creating a harmonic and vivid image.[6] For this reason, many of the printed maps were colored by hand until the nineteenth century. Today, color can be intentionally chosen by a cartographer or predefined by the software – e. g., ColorBrewer,[7] GIS software, web-mapping tools.

1 This paper was funded by DFG: SFB 1199 "Processes of Spatialization under the Global Condition."

2 Jacques Bertin: *Sémiologie Graphique: Les Diagrammes, les Réseaux, les Cartes,* Paris: Gauthier-Villars, 1967; Alan M. MacEachren: *Some Truth with Maps: A Primer on Symbolization and Design,* Washington, DC: Assoc. of American Geographers, 1994, p. 17.

3 Data Visualization depends on the level of measurement, which can be numerical (absolute or relative), nominal or ordinal.

4 See Cedeño Montaña in this volume.

5 Color has always played an important role in the history of cartography. Thus, the absence of color in maps cannot be explained with chromophobia (see Boskamp in this volume). In fact, cartographers tend more to the horror vacui and are afraid of too much white space.

6 Hermann Haack: *Schriften zur Kartographie*, ed. by Werner Horn, Gotha/Leipzig: VEB Hermann Haack, 1972, p. 48.

7 http://colorbrewer2.org, acc. 07–26–2018; see also Baum in this volume.

Jean-François Moreau, Raffaele Pisano, Jean-Michel Correas

Historical and Scientific Note of Color Duplex Doppler Ultrasound and Imaging

> *"It has been shown by reason and experiment that blood by the beat of the ventricles flows through the lungs and heart and is pumped to the whole body."*
> *William Harvey*[1]

The intellectual history of imaging as presented in the following article is a dialogue between historical foundations of science and medical frameworks. The aim of the authors is to explain how the use of colors can improve most recent medical visualization techniques, either by bringing true additional medical information such as for color Doppler ultrasound, or by providing colorizations of the computed medical imaging. While the latter is still aesthetic or educational, we consider the colors in the Doppler image to be phenomenological.

To explain this difference, we will go back to the interconnections between the history of printing and the history of anatomy. At the time when progress in international physiology was developing, printing progressed in Germany under the contradictory influences of Newton and Goethe.

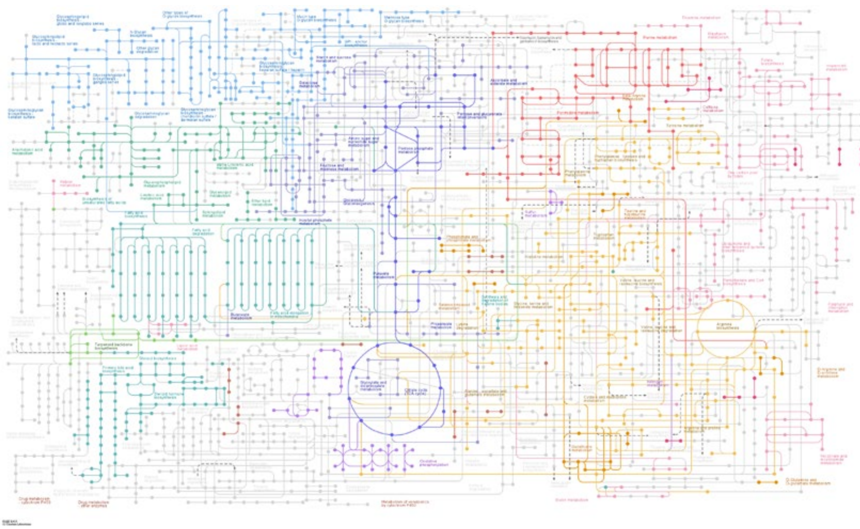
Contemporary printers, even working with offset, used four-color chromolithography (blue, red, yellow and black) to colorize the drawings, especially in anatomy books (e. g., Jean Marc Bourgery's treatise). Under the influence of Malpighi, the oxygenated aortic blood was colored in red, the cava venous system in blue, the lymphatic system in purple or white, the nerves in yellow. This was due to the natural difference in darkness of both the arterial and the venous bloods of live mammals.

In contrast, color Doppler real–time digital ultrasound is the only medical imaging technique using blue and red coding for cardiovascular hemodynamics even though this doesn't rely on oxygen blood saturation. The ultrasonic probe recollecting the echoic waves plays the role of the *heart*. In red the wave figures the blood flow that is coming towards the probe, while the blue wave is travelling

1 Harvey William Harvey: *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus*. Facsimile, Translation and edited by Chauncey D. Leake, Springfield: Charles C. Thomas, (1628) 1928, XIV, (p. 58) p. 103.

Bettina Bock von Wülfingen

Diagrammatic Traditions: Color in Metabolic Maps



1: The metabolic map *Kyoto Encyclopedia of Genes and Genomes*.

Within a fine black frame of approximately 2:1 width to height, the image above (FIG. 1) shows a large number of well-ordered fine parallel vertical and horizontal lines against a white background, connected to one another by half-circular curves, sometimes also by circles and ovals. Where they run parallel, these lines are peppered with dots at symmetrical altitudes. All lines are depicted in eleven different soft pastel and brilliant colors, which dominate specific areas of the drawing; few additional lines are in gray. Salient are two groups of thirteen parallel vertical lines in a bluish-green in the left center. Their design is reminiscent of abstract floral art deco graphics. Apart from the circular forms that build connections between lines, all lines are either strictly vertical or strictly horizontal (in a ninety degree to one another). While the specific areas of the map appear in a specific color, the respective color is repeated in an oval nametag to the respective zone of the graphic that bears the name (written in white against the colorful background) of a metabolic pathway (e.g., on the violet tag: "Energy Metabolism"). In the very center, a long vertical line ending in a large circle in the lower part of the center depicted in violet-blue captures one's attention, bearing the tag "Carbohydrate Metabolism," and on the top

Dominique Grisard

Pink and Blue Science

A Gender History of Color in Psychology

Why do girls love pink? British neuropsychologists Anya Hurlbert and Yazhu Ling believe evolutionary adaptation to be the answer.[1] Their highly publicized 2007 study traced women and girls' preference for pink and reddish tones back to the gender-specific division of labor in prehistoric times. As gatherers, women had trained their eyes to recognize berries as efficiently as possible. Accordingly, they argue that the attraction which pink is said to have on girls nowadays has to do with the evolutionary advantage that enabled women to more easily recognize the reddish colors of berries and thus ensured the survival of prehistoric humans.

Pink is arguably one of the most symbolically charged colors today. Over the course of the mid to late twentieth century, pink has become synonymous with girlie femininity and (effeminate) homosexuality. As I will show in this article, pink's gender and sexual symbolism has undergone a process of naturalization, so much so in fact that it has come to shape scientific research. My contribution focuses on the appearance of pink in the range of colors studied by psychologists. It will address the history of color in psychology in terms of the gradual appearance of the color pink. In the process, the relation between the absence of pink and the presence of other colors, which are attributed specific racialized, gendered meanings, will function as an insightful backdrop. These findings will allow me to show how an epistemological interest in pink and blue coincided with gender differences in early childhood prompting this view to become central to the study of color.

My focus will lie on the continuity of evolutionary meta-narratives in color psychology and in the central epistemological position of the child in these studies. I use the term meta-narrative to denote the epistemologies and stories psychologists draw on to make results meaningful, socially relevant even, results which by themselves would be quite limited in scope and reach. I will reflect on the ways in which science is shaped by processes of naturalization of racialized and gendered binaries. Ultimately, my contribution will make clear that pink and blue do not only color the consumer culture of today's children, they also play a significant part in scientifically explaining childhood gender differences.

1 Anya C. Hurlbert, Yazhu Ling: Biological Components of Sex Differences in Color Preference. In: *Current Biology*, 17 (16), R623-R625.

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Grisard: 1: Gendered Brain, 2019, Kyle Bean (Artist), Originally commissioned for *The Observer magazine* issue February 24th 2019.

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Color makes its way into natural science images as early as the research process. It serves for self-reflection and for communication within the scientific community. However, color does not follow a standard in the natural sciences: its meaning is contingent, even though culturally conditioned. Digital publishing enhances the use of color in scientific publications; at the same time, globalization promotes the idea of universal color symbolism.

This book investigates the function of color in historical and current visualizations for scientific purposes, its epistemic role as a tool, and its long neglect due to symbolic and gender-specific connotations. The publication thus helps to bridge a long standing research gap in the natural sciences and the humanities.

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