An Introduction to the Culture of Light in Relation to Color Design Needs

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ABSTRACT

This article arises from the recognition of the need of an integral approach to the teaching of color and light for the design discipline, as both matters are usually taught separately or not taught at all in the designer's education. More specifically, in the field of Color Design, there are considerations that should be made, regarding to theoretical basis of light which can be very useful to understand the chromatic phenomena, as light contributes to color perception, appearance and meaning. This theoretical foundations are related to the direct perception of light and color, physical characteristics we gradually experience through living, but also about the indirect perception, it means, principles, concepts or models that help to understand or give perspective to experienced phenomena, such as the cultural or conventional meanings of color and light.

KEYWORDS Color Design, Light, Experience, Visual Perception, Education

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Introduction

The beginning of every color experience is a physiological response to a light stimulus. Without light, there would be no vision or color because light and color are inseparable. But when it comes to design, and specifically design education, an integrated approach to light and color is usually not included: these two matters are studied separately or -most of the time- are not studied at all. Traditionally color and light in design and design education have been looked upon as something that is discussed when the design is finished; designed objects or designed spaces are thought to be 'colored' and 'illuminated' afterwards (Klarén et al. 2013). This lack of training is critical if we realize that every day and during the same day, we develop our routines in changing light conditions, due to natural or artificial lighting, that change the different appearance of the colors of materials in the environment and that this affects our relationship with visual communication, the objectual or spatial world, the fields of development of design.

The following theoretical foundations of light are related to the direct perception of color, either because they are part of how we understand the chromatic phenomenon or because they directly affect the color appearance in our environment. Also a revision of some concepts associated to different cultural and meanings regarding the indirect perception of light and color are considered.

1. The visual spectrum

One of the first considerations that we may have when introducing the topic of light into color knowledge is the one of the visual spectrum. Color can be described also as what we see when the light reflected by an object reaches our eyes. Every illuminated body absorbs a part of the light waves and reflects the rest. There are numerous light emitting sources (the sun, fluorescent lamps, incandescent lamps, LEDs, fire, etc.) and each one significantly affects the way we perceive colors. The most important of the light sources is the sun. Sunlight is formed by a broad spectrum of radiations that are grouped into a continuous spectrum that ranges from very small wavelengths (1 picometer = 1pm, equivalent to one billionth of a meter) to very large wavelengths (from more than 1 kilometer). Each visible wavelength defines a different color. The human being is only able to visualize a subset of the existing wavelengths: those ranging from 380 nanometers (1 nanometer equals one millionth of a millimeter), which correspond to the violet color, up to 730 nanometers, which correspond to the color red. This portion of colors we see is called the visible spectrum.

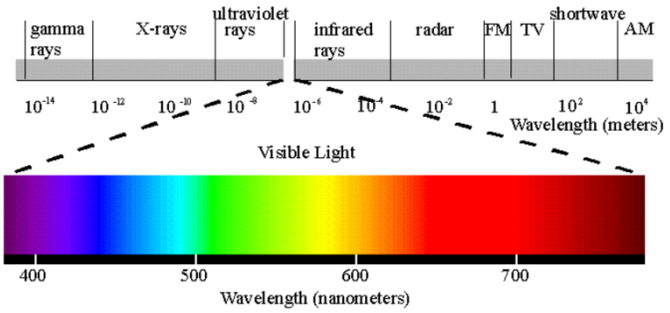

Image 1: schematic representation of the visual spectrum

The usual knowledge of color comes from two great sources: one is the scientific one, which comes from experiments and tries to establish laws that explain the phenomenon of color; and the other is a product of the intuition of philosophers, writers, painters. But following the line of the visible spectrum, it is possible to point two of the most relevant references: the first came from Isaac Newton and his *Opticks.* Newton first occupied the word spectrum (appearance or appearance in Latin) when describing his experiments in optics. It was based on an experiment of white light decomposition, which led through a prism and thus obtaining the light spectrum. He proved that the white light was constituted, in fact, by a combination of all the colors of the rainbow, and that the different colors in which the light was divided moved at the same speed through the air, but at different speeds in the transparent crystal. For example, red light travels faster in the glass than violet light. In this way, the colors are arranged from red, one after the other, forming the spectrum. Newton divided this spectrum into seven colors: red, orange, yellow, green, blue, indigo and violet. He chose these seven colors of a belief, derived from ancient Greece, that there was a connection between colors, musical notes, bodies in the solar system, and the days of the week (Hutchinson 2004). He called primary triad or simple colors to red, yellow and blue, and their mixtures, complementary or secondary: green, violet and orange. He also observed that natural light, when it hits an element, absorbs some of these colors and reflects others. With this observation, it gave rise to the following principle: opaque bodies, when illuminated, reflect all or part of the components of the light they receive.

Other explanation of the spectrum is experimental and was done by Johann Wolfgang von Goethe in his *Theory of Colors,* who argued that the continuous spectrum is a complex phenomenon, opposing Newton. Goethe observed that with a greater opening of the light beam, the spectrum is lost; a reddish-yellow border and the other blue-cyan border are manifested, with shades of white between them, and the spectrum is only raised when these edges are close enough to the overlapping colors. Goethe

said that 'colors, therefore, to begin with, make their appearance purely and simply as phenomena on the border between light and darkness' (Goethe 1992). His theory contains one of the first and most accurate descriptions of phenomena such as color shadows, refraction, and chromatic aberration. Newton saw the white light composed of different colors and Goethe saw the color, as a result of the interaction of light and darkness. This last theory, more experimental and physiological than physical, was not well received by modern physics, which based on the theories of Newton and Huygens, define darkness as an absence of light. Young and Fresnel, combining the theories of Newton and Huygens, demonstrated that color is the visible manifestation of the wavelength of light. Although his theory has been rejected over time, for Goethe it was very important to understand the human reaction to colors, he spoke of 'demands' of color, which are nothing but the subjective part of color and his research was the cornerstone of the current meaning of color.

2. Light and color temperature

An object capable of absorbing light of all wavelengths is called a black body. The color temperature of a light source is the temperature of an ideal black body radiator that radiates light of comparable hue to that of the light source. The basis of color temperature measurement started with William Kelvin in 1848 when he heated a block of carbon and noted the color changes as the temperatures increased. Initial colors detected were a slight glowing red that changed to yellow and finally reached blue shade white at its highest heat (Kumar & Choudhury 2014). This is the basis for the Kelvin color temperature scale. The different light sources have a different color temperature. For temperatures ranging from 2.000 ºK to 20.000 ºK, the black body emits light with dominant colors that goes from red, yellow, white, violet until blue.

Image 2: comparison between different color temperatures and how it affects color appearance

3. Color standard illuminants

Related to color temperature, an illuminant is a measurement standard for light sources. Standard illuminants provide a basis for comparing images or colors recorded under different lighting. Illuminants define a spectral energy distribution or SPD curve of the light source. The SPD of a physical or real light source depends on several factors and varies widely. Sunlight or daylight varies according to geographical location, weather, time, etc. The energy distribution of an artificial lamp depends on age, applied voltage, etc. (Kumar & Choudhury 2014).

Some of the most used illuminants are: illuminants A, for light sources with a warmer temperature lower than 5000 ºK, which represents incandescent tungsten filament lamps; illuminants B and C represent direct and shady daylight respectively; illuminants D, for mostly white light sources related to daylight and a temperature around 5.000ºK and 6.500 ºK (illuminants D50, D55, D65, D75, among others); and also illuminants F, for cold light sources such as fluorescent lamps (illuminants F2, F7, F11, among others).

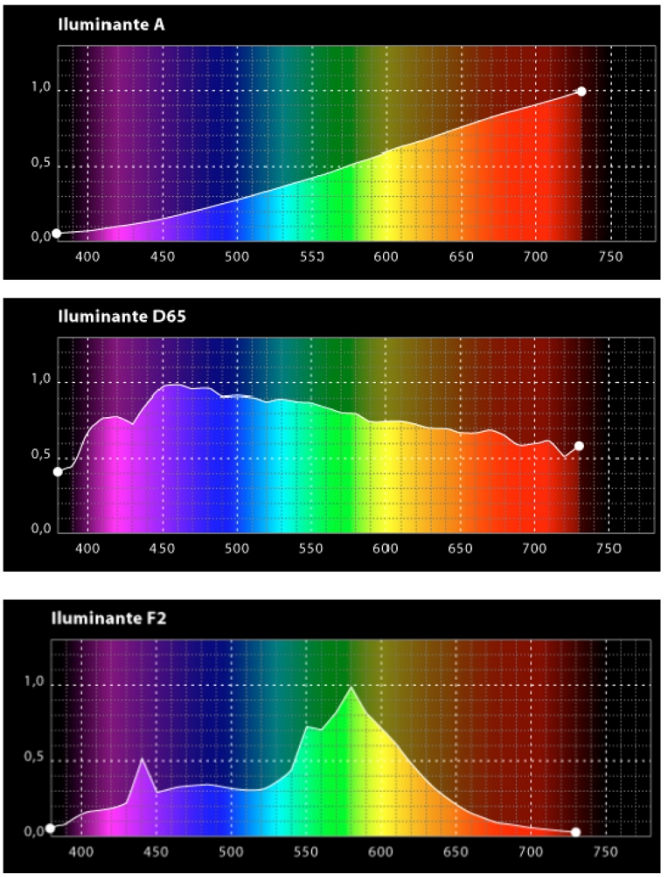

Image 3: comparison between the spectral energy distribution for different illuminants: A, D65, F2.

4. Light direction and diffusion

The direction from which light touches the surface of an object influences our perception of shape, color, texture and volume, because it is directly related to the conformation and width of shadows. With the creation of shadows, the color palette grows into more complex or tertiary colors, because the attribute of value is affected, this means the relative lightness or darkness of a color, that it is also an important tool to add emphasis and establish visual hierarchy within a composition. Strengthening the light thrown upon colors lightens them. Decreasing the light causes colors to appear darker, and the changes which may thus be effected are infinite in range and variety. The direction of light will be also related to the creation of positive or negative meaning in communication, as it can affect the perception of drama or safety, just to name a few.

Image 4: the use of light direction to increase the perception of drama and is one of the main features in the work of the Italian painter Caravaggio. Caravaggio, Judith Beheading Holofernes, 1598–1599. Oil on Canvas, Rome, Galleria Nazionale d'Arte Antica.

Diffusion describes the transition between highlight and shadows. Diffused light passes through a semi-transparent material on the way from the source to the subject. Diffused light creates shadows with lower contrast and softer edges than direct light (Arena 2013). Clouds are a great example of how sunlight can be diffused. The water vapor causes the light to bounce around and come at the subject from many angles rather than directly from the sun. Any light can create hard or soft lighting depending on two factors: size, not only the size of the practical lighting source but also the size in relationship with the subject that is being illuminated; and distance, in relation to the subject and the placement of the lighting source. In terms of color, diffusion will create the perception of a wide amount of different hues because it has an effect in color saturation or intensity, providing to the viewer different chromatic grays, of medium-low, medium and medium-high intensities.

5. Color appearance: metamerism and constancy

As color perception is due to light and light is always changing, color appearance is also always changing. The local color of an object is rarely the color which the eye sees. Color is a very relative resource. Two of the most common color phenomena that are related to light as a factor of change in the perception of colored objects are metamerism and color constancy.

Metamerism is the term used to describe -on one hand- the fact that two lights with different proportions of energy at certain wavelengths may produce the same perception of color (illuminant metamerism). It means that two colors appear to match under one lighting condition, but not when the light changes. Metameric matches are quite common, especially in near neutral colors like grays, whites, and dark colors like these. On the other hand, metamerism can also be used to describe the phenomena in which the same light may produce different perceptions of color in different observers (observer metamerism) (Best 2012).

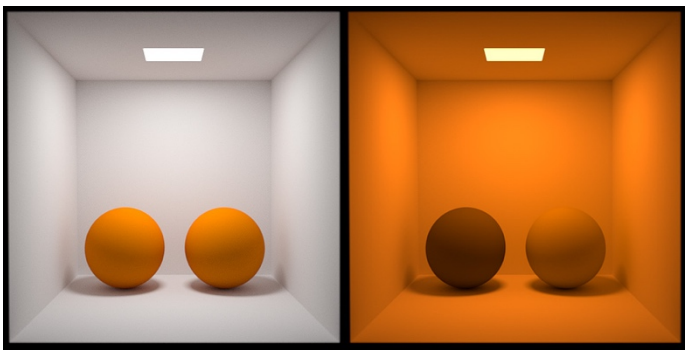

Image 5: metamerism is when two color samples appear to be the same in one given light situation (left) and different in other light situation (right).

Color constancy is a term used to describe the ability of the human eye to compensate for common changes in illumination and viewing conditions that affect the color of a particular object. We can easily describe the color of an object by looking at it under white light. Under a different illumination, we may still be able to name the color of the same object, but perhaps not so easily. Light and color reflected from the object may vary greatly with changes in illumination. Color constancy is a form of eye adaptation to the prevailing illumination. The eye adapts similarly to changes in brightness. The eye–brain system apparently works to discount the color of the illumination using several

cues: the lightest object in the visual field is usually white, and the overall color of a scene should be approximately neutral.

Image 6: we talk about color constancy when different samples tend to retain approximately their appearance when they are observed under different light conditions. What it is perceived as white (or the lightest color) continues to be perceived as white in a different light condition.

Both, the chromatic adaptation of the human visual system and the chromatic contrast phenomena occur and play a role in color constancy. Differential adaptation in the cone receptors helps us to discount the color of the illumination in the environment.

6. Indirect perception: light and color in cultural meaning

In addition to the basic perceptual processes and the direct spatial understanding of the world around, human comprehensive experience of color and light is also related to culture. Imaginations, conceptions and ideas about the world provide a context to our sensory experiences. Being embedded in cultural expressions (history, traditions, customs, trends, scientific theories, art, poetry, etc.), indirect experience forms a cultural context to which all experiences of necessity are related (Klarén et al. 2013). History, scientific theories and theoretical models provide a basis of explanation and analyses.

One of the most relevant associations of color and light in terms of meaning comes from Goethe's *Theory of Colors,* and specifically from his theory of the chromatic polarities in nature, the light-dark polarity. This concept has its correspondence in other dual principles that affect the organic behavior of nature, and that Goethe would adopt towards 1790 primarily from his relationship with the German philosopher Friedrich Schelling, the main promoter of the German idealist current called the Philosophy of Nature or *Naturphilosophie,* whose intention was 'to be able to present a complete system of knowledge about nature' (Schelling 74). At its foundation, the *Naturphilosophie* defended an organic conception of science, in which the subject played an essential role, conceiving the world as a projection of the observer. This current also sought in nature a separating principle, an opposition law where there are forces of the opposite sign: polarity. In the dynamic conception of Schelling's nature, the duality of opposing forces constitutes the beginning of all movement and the source of all activity. Schelling defines polarity as an 'identity in duplicity' or 'duplicity in identity' of all natural phenomena, from gravitation, magnetism, electricity, chemical affinity to sensitivity, irritability, and the tendency to the proper organization of life, affirming that this play of forces is the vital essence, which would originate from the dualistic opposition of subject and object.

For Goethe, active participant of the *Naturphilosophie,* the idea of polarity is related to these dual principles in very different manifestations, which the poet has as constituents of organic life: attraction and repulsion, positive and negative electricity, magnetic poles, feminine and masculine, light and shadow, inspiration and expiration, etc. (Arnaldo 26). In 1790, he wrote the scientific essay *Polarity (Polarität)*, where he refers to some fundamental associations of phenomena such as 'light and darkness', 'body and soul', 'spirit and matter', 'real and unreal', 'left and right', 'inspiration and expiration', among others. The fundamental polarity of the *Theory of Colors* will be given by a symbolic relationship between light and darkness and its link with the subject: 'the black, representative of darkness, leaves the visual organ in a state of rest; on the other hand, the white, lieutenant of the light, excites him' (§18), this polarity the poet will address it transversely from the first sections of the *Theory* and will expand it later -when developing his circle of colors- to other chromatic polarities, such as temperature, 'warm and cold', or active and passive colors, among others.

From Aristotle and forward, it is possible to find allusions to colors as tensions between light and dark, which Goethe deepens by reading Athanasius Kircher and Lazare Nuguet [1]. In a similar way Leonardo Da Vinci refers to the appearance of color in the different objects, in some passages of his *Treatise of Painting.* Goethe reinterprets this tradition, and for him this reciprocity between darkness and light pointed to what he called *Urphänomen* or archetypal phenomenon of color [2]: color as a result of the tension between darkness and light. Darkness for Goethe is not an impassive and total absence of light as Newton had suggested, but, rather, a dynamic presence, which opposes and interacts with the light. In the preface of his *Theory,* he coined a phrase that has become famous: 'Colors are acts of light; acts and sufferings' (Goethe 57), which continues in the following paragraph, in relation to Nature: 'In this sense we can expect [colors] to illustrate us about the nature of it [light]. Although colors and light have very precise relations with each other, both those and this one belong in a whole to Nature; because through

them Nature wants to manifest itself particularly to the sense of sight' (Op. cit).

By 'sufferings', Goethe understands the moments when light acts as a passive entity in the perception of color. The symbolic opposition between light and shadow will also appear in some of his poems, and other examples of this image are presented in Faust, referring to spatial colors (Arnaldo 21). In the *Farbenlehre,* on several occasions, Goethe refers to all colors as borders between light and dark, in its close relationship to the black and white achromatic tones, and from them, the two colors or poles will be generated that they are for Goethe the fundamentals or primaries: yellow, the brightest shadow, 'on the active side, next to light, clarity, white is born yellow' (§503), and blue, the darkest shadow, 'in the same way, on the passive side, next to darkness, darkness, black, blue appears immediately' (§504). These polarities, active and passive, define the structure of the two arcs of the color circle of Goethe: the active arc is composed of the colors red-purple, orange and yellow and is represented by the poet with a positive sign or '+', while the passive arc is composed of the colors green, blue and violet, and is assigned the negative sign or '-'.

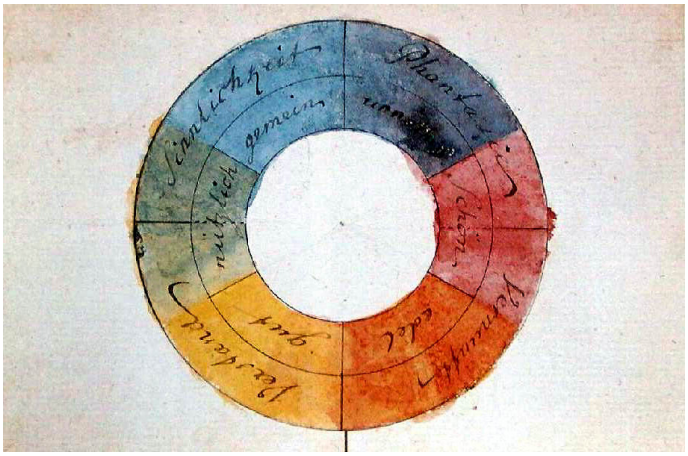

Image 7: Goethe's symmetric color wheel with associated symbolic qualities, 1809. The light or positive side of the circle is red, orange and yellow; the negative or dark side corresponds to the green, blue and violet.

In other fields as literature, light and darkness continue to be perceived as a polarity. Darkness symbolizes the end, since light is the beginning. This polarity establishes the difference between good and evil, also between day and night. Darkness is often used to convey negativity: evil, death or the unknown. Light is usually related to something positive: goodness, life or hope (Kampf 2017). Light and darkness metaphorical meanings are also often related to life and death. Light is a symbol for or the primal conditions of life: warmth, sensuality, and intellectual and spiritual enlightenment. Darkness, on the other hand, is associated with chaos, death, and the underworld: is the mysterious, impenetrable ground and source of light. Light is often related to the cultural and symbolic associations of colors white and yellow. When is conceptually perceived as related to white, their associations are mostly positive, pure and brilliant. When related to yellow, is also energy, understanding and enlightenment. Darkness is usually perceived as related to the darkest colors of the spectrum, black and violet. When related to black its associations become mostly negative, is the no-color, or the absence of all colors, it is passive as the shadows. Black also reverses all positive meaning of any bright color. When related to violet, darkness becomes mysterious, it is magic, the hidden, fantasy, the transmigration of souls and the esoteric. Darkness becomes superstition (Calvo 2008).

Although these meanings correspond mainly to a Western view of the language of color and light, and designers should not abide by a specific conception of meaning, the polarity of light and darkness in relation to the concepts of positive and negative is almost universal. This means, instead of looking for a specific association of colors (understood as hues) with a certain pre-established meaning, a more correct use of the associations of light and darkness to the chromatic meaning could be applied when establishing a parallel with the property of color that is called 'value', and which is understood as the 'amount of light or darkness of a specific color'. In other words, associating the value of the different colors (and not their hue) with different amount of light or darkness could be the way to determine their meaning, without falling into pre-conceptions that may exclude a specific culture. Thus, the same color (hue) could serve to represent positive or negative meanings, if we associate it with more light or more darkness, that is, if it is a light or dark tone of the same color, expanding the possibilities of a specific color palette. Experiencing color and light in a living context always includes emotional and intuitive understanding; we experience spontaneously spatial relations and moods in a cultural context.

Conclussions and comments

When it comes the time to plan an educative instance for color training in design, it is necessary to take into consideration some of the basic knowledge of light, as it affects the experience of the chromatic phenomena. The amount of theoretical fundaments about light can be really huge as the complexity of the resource, and the selection proposed by this article is a preliminary guide to consider the more relevant aspects that play a role in direct and indirect color perception. There are also other considerations to be made regarding the visual system and the eye that were not included in this paper because

of the extension of the complexity of the issue, but that should be also present in the fundamental explanation of visual perception of both, color and light. Usually, a contextual or cultural approach regarding light and darkness is also missing in the teaching of color design, but as the design discipline is profoundly related to message and meaning, they were included in order to provide some guidance for teachers and curricula planners. Further development of this research may consider the interplay of light and color in terms of experience design, design for wellbeing and interface design.

Conflict of interest declaration

I declare that no financial o personal interests have affected my objectivity, and this investigation has no conflicts of interest.

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Notes

[1] In the Historical Section of the *Farbenlehre* there are specific references to the works *Ars magna lucis et umbrae,* published by Kircher in 1646 and to the essay on color published by Nuguet in the *Trevoux Journal* in 1705.

[2] The *Urphänomen* or archetypal phenomenon of Goethe is a concept used in most of his scientific essays and corresponds to the "essential pattern or process of a thing or phenomenon", the "fundamental nucleus of a thing, which defines what it is and in what will it become". The philosopher Friedrich Schiller complained to Goethe that this concept seemed to be a synonym for the Platonic *"idea",* but Goethe rejected the comparison. (Seamon & Sajonc 22)

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