PDHonline Course R148 (2 PDH)

Engineering Ethics: Color and Technology

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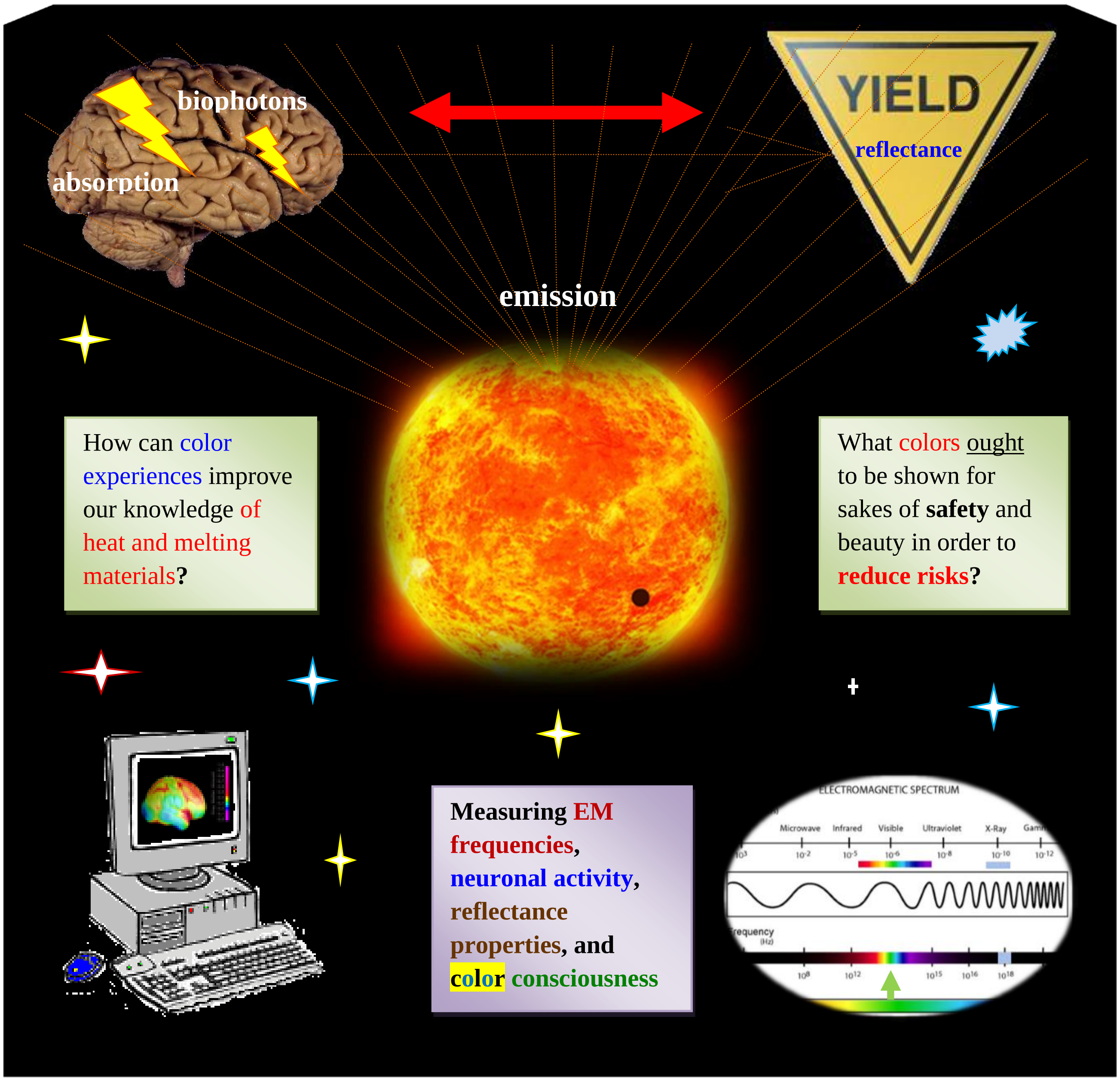

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COURSE CONTENT

MOST EXCITING AND BEAUTIFUL TECHNOLOGIES OF OUR LIFETIMES

Colors matter! Anyone who has ever taken a color eye exam in school, for a driver's license, and especially the Ishihara test for an FAA pilot's medical knows how important it is to pass the test. Patients who fail these tests see a world without certain colors or, worse, no color at all, and, therefore, they experience the world with the absence of the reds, yellows and oranges for signs and **signals for danger!**

When we see things that are colored, the light from objects in the environment physically absorbs within the back of the retina of the eye. Photoreceptors are located within the retina, which are called "rods" and "cones." Rods and cones are nerve cells that respond to different types of light. Rod cells respond to dim light more, and cone cells function better with brighter lights.

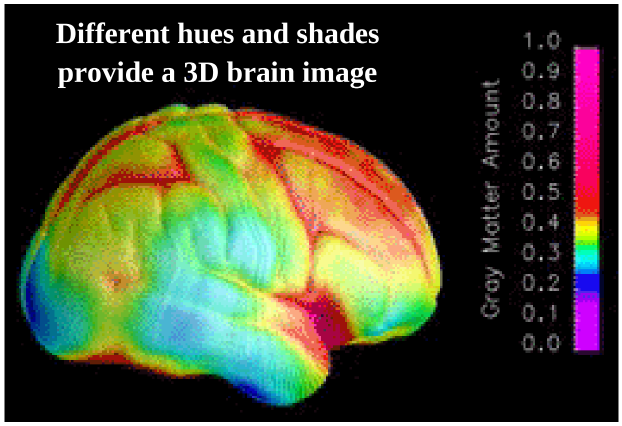
Cones are color selective and typically consist of three kinds of photoreceptors (i.e., **short-, medium- and long-wavelength cone cells**, which respectively absorb blue, green and red wavelengths of light). Cone cells have proteins that absorb the light, which triggers changes within the photoreceptor cells. Neural signals travel via bipolar cells to the ganglion cells, then these neural cells transfer the neural information from the eye all the way to the very back of the brain and region of the visual cortex, which gives us color perception and conscious experiences of color.

Color Science combines with neuroengineering and neuroscience to be the most exciting set of technologies of our lifetimes. However, they may develop into some of our greatest ethical challenges yet!

Neuroscience and neuroengineering will affect each of us within the next two decades, directly or indirectly, individually or through our friends and families. Neuroscience continues to change the ways we think and behave. Color sciences, such as colorimetry (i.e., the scientific description of color, involving the specification of relevant properties of color for various types of materials), involve neuroscience and engineering (e.g., functional Magnetic Resonance Imaging fMRIs), computer science and graphics (e.g., See **Fig. 1** below), which require an observer, light source, colored graphics, and an object with reflectance properties (i.e., objects that reflect light).

What we mean by **"neuroscience"** is the science of nervous systems, which includes the nature and significance of brains and nerve fibers, weaving through our bodies. Neuroscience focuses upon the nervous system, utilizing the disciplines of math, biology, chemistry, physics, psychology, philosophy, computer theory, and research design (Moreno, 2006). **"Neuroengineering"** is defined as the interdisciplinary field of engineering and computational approaches applied to problems in basic and clinical neuroscience.

Fig. 1 fMRI computer generated brain images involve color



"Color science" is an interdisciplinary field that involves any or several of the following disciplines and their interrelations and relevance to color: mathematics, computer imaging science, computer science, physics, chemistry, psychology, physiology, textiles, engineering technology, graphic or fine arts as well as those disciplines that relate to quantitative descriptions of colors.

The questions with which we are concerned are: **What engineering technologies are directly related to color? Why is such science and its applications in the engineering of color related technologies in need of ethics, ethical guidelines, moral awareness and moral responsibility?**

We seek to guide you through your own appreciation of "engineering ethics of color, color science and color technologies" and the decisions and ethical choices you make related to a most important and rapidly developing interdisciplinary field.

Undoubtedly, color is one of the most fascinating subject matters because color transcends most academic disciplines and involves mixes of studies and practices in order for any potentially comprehensive understanding of color to develop. Studies of color range from physics and chemistry to psychology of sensation, perception and consciousness as well as the practical fields of engineering and architecture. Obviously, architecture and engineering may also be viewed for their contributions to art and color.

Despite the study of color in so many sciences and arts, what might be questionable is an "ethics of color," or, more specifically, an **engineering ethics of color**, ethics of color science and related moral issues concerning associated technologies. **Why should engineering ethics pay attention to color-related themes?**

One way to explain the importance of engineering ethics of color is to consider that **color never arises without light**, and light consists of photons, which are different frequencies within the electromagnetic spectrum, ranging from destructive gamma rays, X-rays and UV rays to the color spectrum, infrared, microwaves and radio waves. **Thus, lighting, heat, observers affected by lighting, and objects that emit light are all relevant to engineering ethics of color.**

Even engineering feats, such as real-time fMRIs, are interrelated with color science since they produce colored images that allow neuroscientists to interpret the functions of the human brain. These colored images sometimes illustrate the neural correlates of consciousness of colors. That is, neuroscientists know the brain regions associated with the conscious experiences of colors, and the associated brain activity with consciousness is called the "neural correlates of consciousness."

Perhaps one unique way of describing what should come to mind during the development of engineering ethics of color is first to consider the deficiencies that result from colorblindness. There are two major types of colorblindness. The first type of colorblindness results from a lack of some type of photoreceptors in the retinas of the eyes (i.e., usually one type of cone either short-, medium, or long-wavelength cone is absent, which creates a type of color blindness). The first type of colorblindness (i.e., normally characterized as **dichromatic colorblindness of the eyes**) is a condition that inflicts between five and ten percent of males.

The second type of colorblindness is a much more severe and infrequently occurring condition, namely, **colorblindness that results from brain damage** to certain areas of the visual cortex (e.g., the V4 area). It is the latter condition of colorblindness that will allow us to better pinpoint the relevance and importance of applied ethics within the fields of engineering, color science and architecture.

Moreover, it is perhaps especially important to consider the ethics of color within male-dominated fields, such as engineering and architecture, in order to understand some of the related shortcomings concerning vision (e.g., colorblindness), which may account for even more than ten percent of a workforce of engineers.

In cases of severe colorblindness, colorblind people are unable to distinguish between (or consciously experience) colors at all, and thus they cannot determine the **colors of flames and colors of solid and liquid metals.** Color differentiation serves as the most fundamental (or primitive) way that engineers, welders, blacksmiths etc. can tell how hot certain objects are.

Fig. 2 Yellow Molten Wrought Iron at ~2800°F

For instance, in the midday sunlight it can be important for one to know that wrought iron is approximately **1,400°F** when it is red, about **2,000°F** when it is orange and around **2,500°F** when the iron is bright yellow before wrought iron melts at about 2,800°F, which is shown in **Fig. 2** (Saracco, 2013). http://www.personal.psu.edu/cms5480/blogs/saracco/project-4.html).

So, it appears obvious that certain types of colorblindness place people who work with **dangerously hot materials at greater risks**. It might well be considered unethical to employ colorblind individuals in a workplace situation that includes extra risks for those who lack color experiences, or testing individuals is another alternative. **In essence, it is ethically necessary to take precautions within the workplace so that colorblindness does not allow safety standards to be compromised.**

There are also many other examples in engineering which lead us to conclude that color, color science and technology must be viewed through our inner senses of morality. Our inner senses of morality allow us to come to ethical understandings of the processes and productions of engineering with respect to color technology as well as color and its ever important roles involved in safety hazards.

For example, because machinery is typically colored and many important messages and signals are colored, such as "signs and **Warnings**," **it is relevant to ask whether more color, different colors, or specific color combinations ought to be applied in order to improve safety instructions and measures where we work with dangerous machines and hazardous materials**.

Inquiries concerning alternative color combinations have been a subject of human factors engineering since World War II.

Additionally, colorblindness results in different personal tastes or preferences for the art and aesthetic qualities of our surroundings, which are especially important within the workplace. Even the lighting of the offices and warehouses are important for the daily experiences of employees surroundings, job applicants' impressions and overall appeal to customers involved in the commercial aspect of architecture and engineering.

Hence, an ethics of color should not be ignored in virtue of our satisfactions and pleasures for aesthetic qualities of artful objects and warnings associated with danger which demand consideration for the engineering ethics of color.

I. Color Science and Color Technology

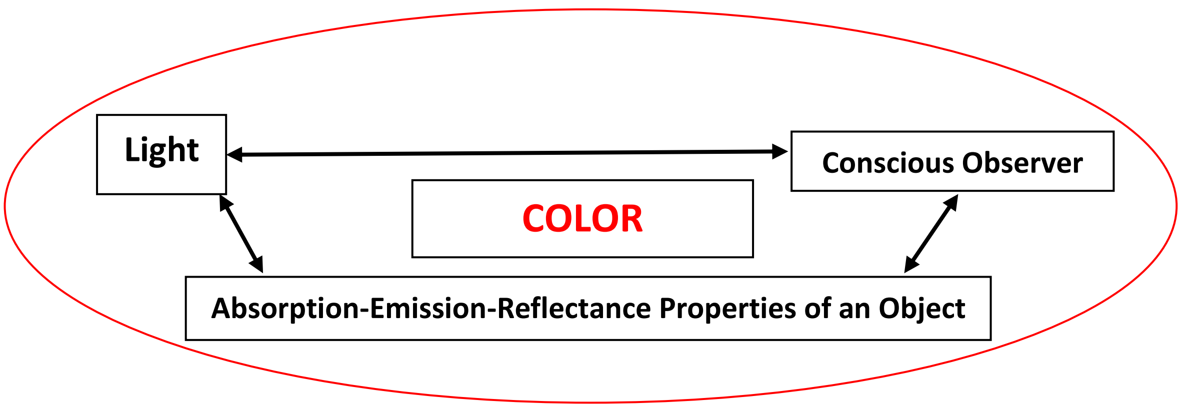
What is Color?

"The term *color* is commonly used in three distinctly different senses. The chemist employs it as a generic term for dyes, pigments, and similar materials. The physicist, on the other hand, uses the term to refer to certain phenomena in the field of optics. Hence, the physicist, when confronted with the task of measuring the color of a material, measures the relevant optical properties of the material. Physiologists and psychologists employ the term in . . . another sense. They are interested primarily in understanding the nature of the visual process, and use the term, on occasion, to denote sensation in the consciousness of a human observer." (MacAdam, 1985, 3-4)

"Color" is a type of relation concerning various levels of observation, which involves a complex interaction between light, the absorption, emission and reflectance properties of objects within the environment, and their interrelations with the observer. Figure 3 illustrates color as a complex interrelation.

The conscious observer is important in relation to light that is directed toward the observer's visual system. For instance, some of the rays of light (e.g., x-rays, which is emitted by electrons) travel through the entire visual system and penetrates through the skull of the human observer, but light within the range of the visible spectrum only enters the visual system via the eyes. Some of the light reflects and scatters away from the visual system, especially from the white part of the eyes (i.e., the sclera).

Fig. 3 Color: The Relation between Light, Properties of Absorption-Emission-Reflectance, and their Interrelations with the Observer



Yet some of the light absorbs into the human visual system and causes chemical reactions, which are positively correlated with conscious experiences of color (i.e., important to the NCC (Neural Correlates of Consciousness) project within the neurosciences). Lastly, the visual system, which is made up cells, and the rest of the cells of the body emit "biophotons." Thus, the human body itself creates very weak rays of light via each of the trillions of living cells of the body (Rahnama et al., 2011). Some neuroscientists are using light to communicate with neurons in the brain.

Typically the "color spectrum" is solely considered with regard to color, despite the fact that chemical elements, such as radium emit light that leads to color sensations, even if the material is presented closely behind the head of the conscious observer. Additionally, x-rays under certain conditions are visible and lead to experiences of color (i.e., bluish-gray sensations, which was noted by the Nobel Prize winner Wilhelm Roentgen; See **Fig. 18**). X-rays increase health risks, like ultraviolet and gamma rays, which consist of photons of higher energy levels on the electromagnetic spectrum, which can damage cells.

"So much of interest happens in this narrow region of the electromagnetic spectrum because these are the wavelengths where interactions of light with electrons first become important. Waves of lower energy mainly stimulate the motions of atoms and molecules, and so they are usually sensed as heat. Radiation of higher energy can ionize atoms and permanently damage molecules, so that its effects seem largely destructive. Only in the narrow transition zone between these extremes is the energy of light well tuned to the electronic structure of matter" (Nassau, 1980 p. 154).

Figure 4 describes three common ways of describing the ranges or dimensions of color, which are related to **colored lights**, with which you may be reading and observing the content of our course via the lighting of your computer monitor, and the **colored paints, inks, dyes** etc. with which you may have printed the material of our course together. (**Fig. 4** was adapted from Shevell (2003, 194))

Fig. 4 The Munsell System of Color Orders: Lightness, Chroma and Hue

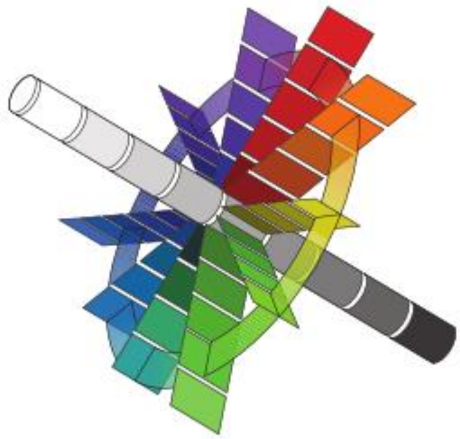


Fig. 4 illustrates a set of Munsell chips that are utilized for the purpose of demonstrating a system of colors with **gradations of lightness**, which are shown via the range of colors that we judge as having the same lightness as the color white (i.e., white holds the numerical value of 10) to the color black (i.e., having a numerical value of **0**). The gradations of lightness involves the light colors and dark colors but only with respect to their ranges from bright to their amounts of darkness.

Additionally, this system of colors consists of **gradations of chroma**, and they are represented with the pegs in the white, gray and black rod. Lastly, the final range or dimension of color consists of the **gradations of hues**, and they range in the same order as the EM or electromagnetic spectrum with respect to the visible portion of it (i.e., red, orange, yellow, green, blue, indigo and violet), although they are placed within a circle.

So far we have provided you with two very different types of descriptions of "color." The **first description** describes briefly what the "necessary conditions" are in order for color to arise, namely, the **light** that shines on an object, which has different **reflectance**, emission and absorption properties than other objects, and which therefore allows the **conscious observer** to undergo conscious experiences of color concerning that object, which are different from other objects.

Our **second description** incorporates the Munsell system of color orders and identifies colors in accordance with three sets of ranges, namely, **lightness, chroma and hue**.

Figure 5 illustrates the diversity of colors of medicines, which is related to the affect that the pills have upon subjects insofar as the colors of the pills can increase the placebo effects. For instance, blue pills can more readily increase the placebo effects of downers, and red pills can increase the placebo effects of uppers. Moreover, if a company changes the color of the sort of pill that it mass produces, then there is a greater chance that a larger percentage of people will discontinue its use.

According to Kesselheim et al. (2013, 202) within a study including over 11,000 patients, "{g}eneric prescription drugs are bioequivalent to brand-name versions but may not have consistent color or shape, which can cause confusion and lead to interruptions in medication use . . . Changes in pill color significantly increase the odds of nonpersistence; this may have important clinical implications."

Fig. 5 Color Science: Medicines and Health

(PHOTO: SHUTTERSTOCK)

January 2, 2013 • By Michael Todd • No Comments and 12 Reactions

New research finds that when generic pills don't share the colors given them by their original makers, patients stop renewing their prescriptions at a higher rate than if they just kept taking the old-style, brand-name medicine. "The color of a pill does have clinical relevance," *The New York Times* quoted the study's lead author, Aaron S. Kesselheim.

What our example in **Fig. 5** and Kesselheim's et al. (2013) work demonstrate is that there are multiple types of measurements and technologies that coincide with color measurement, color science and color technology. For instance, the placement of consumer products at eye-level positions, allowing light to more frequently bounce into the average consumer's eyes, and the colors of products' packages tend to affect consumer habits insofar as companies are able to raise their prices in relation to similar products, and thus people are apt to spend more money on the basis of shape, placement and color.

Babin et al. (2003, 541) maintain that "{f}or fashion-oriented stores, blue interiors are associated with more favorable evaluations, marginally greater excitement, higher store patronage intentions, and higher purchase intentions than are orange interiors. However, the results change substantially when the effect of lighting in combination with color is considered. The use of soft lights with an orange interior generally nullifies the ill effects of orange and produces the highest level of perceived price fairness while controlling for price."

Undoubtedly, color science is interrelated with a large aspect of consumer science and consumerism, which require their very own special subsets of ethics that should be utilized in order to reduce deception, to treat others with dignity and respect, and in order to increase safety and good health within society.

II. Architectural and Engineering Ethics: Color, Beauty and Work Conditions

Every type of engineering and architecture involves color from the historically gray and shadowy industrial warehouses, which are homes for much of our engineering technology, to the mirror reflections of the entire color spectrum, towering over all major cities from the tops to bottoms of some skyscrapers. Colors affect us psychologically throughout our life spans in our cribs and in our workplaces where we are either uplifted by warm colors or dispirited via cold colors.

Fig. 6 Japanese Warehouse

Figure 6 shows the Takashi Yamaguchi and Associates architectural work of an approximately 25,000 ft² warehouse in Osaka,

Japan. The warehouse successfully creates an image of part of a working environment, of which the employees can be proud.

Fig. 7 Lighting and Colorful Pallet Racking for Warehouse Interiors

Figure 7 shows part of the interior design of a warehouse with sufficient lighting and pallet racking that is multi-colored and very efficient.

Yellow is the color that typically stands out the most to human color perceptions, especially when it is accompanied with its **complementary color** (e.g., **blue-yellow** and **red-green**, which create very strong contrasts). So, it is appropriate for yellow to be placed accordingly in order to prevent accidents with forklifts and other equipment that must use the visibly contrasting lines of the racks as guiding tracks.

Thus, we are confronted with **colors** as an important aspect of **visibility**, especially in relation to **artificial lighting**, which are all crucial with respect to **the increase of safety standards, which requires moral decision-making**.

Perhaps colors affect many of us in more profound ways than others (e.g., sparking creativity, comfort, and even joy as opposed to aggression, boredom and discontent). Despite colors' affects on any individual, **engineering ethics involves an understanding of colors, their psychological affects upon us as well as <u>virtuous</u> contributions to the human environments we create with them**.

These virtues that contribute to the production of more idealistic human environments are **thoughtfulness, kindness, respectfulness and fair-mindedness** in regard to our own contributions to other people's environments as well as our own. Another way of viewing the relation of the engineering ethics of color to virtue ethics is to conclude that there is a moral responsibility for employers to prevent their employees from working in ugly and depressing environments, if the costs of such changes are feasible.

The structure of the environments and potentials for optimal lighting are often the responsibility of architects. So, the moral decision-making begins with the blueprints and designs that ought to take natural lighting and heat into consideration. For instance, it often presents an additional challenge for employees who face uncomfortable amounts of sunlight or a complete absence of natural light, which employers should at the very least recognize.

Civil engineers who design, construct and maintain bridges and roads must take natural lighting into consideration so that drivers are not blinded during peak hours. They are morally required, if not legally obligated, to assure that artificial light is sufficient at night and during changing weather conditions. Colors ought to properly demarcate lanes, hazards and other relevant information, such as the information that the solid yellow lines give drivers so that they refrain from passing other drivers, as shown in **Figure 8**.

Fig. 8 Road Optimization of the Visibility of Lanes with Color

Fig. 8 illustrates the optimization of color contrasts upon roads, which is crucial for driver safety. Colors fade over time and thus require constant attention and overlaying in order to increase the recognitions of the drivers' of the lanes, in which they are supposed to remain.

Moreover, it may very well be ethically incumbent upon Federal, State, or Local authorities and engineers to provide consistent and appropriate road markings to avoid confusion to drivers. Inconsistent and inappropriate road markings could lead to dangerous consequences or death, particularly during construction or stormy weather.

Fig. 9 Ambiguity of Lanes without Optimization of Color Contrasts

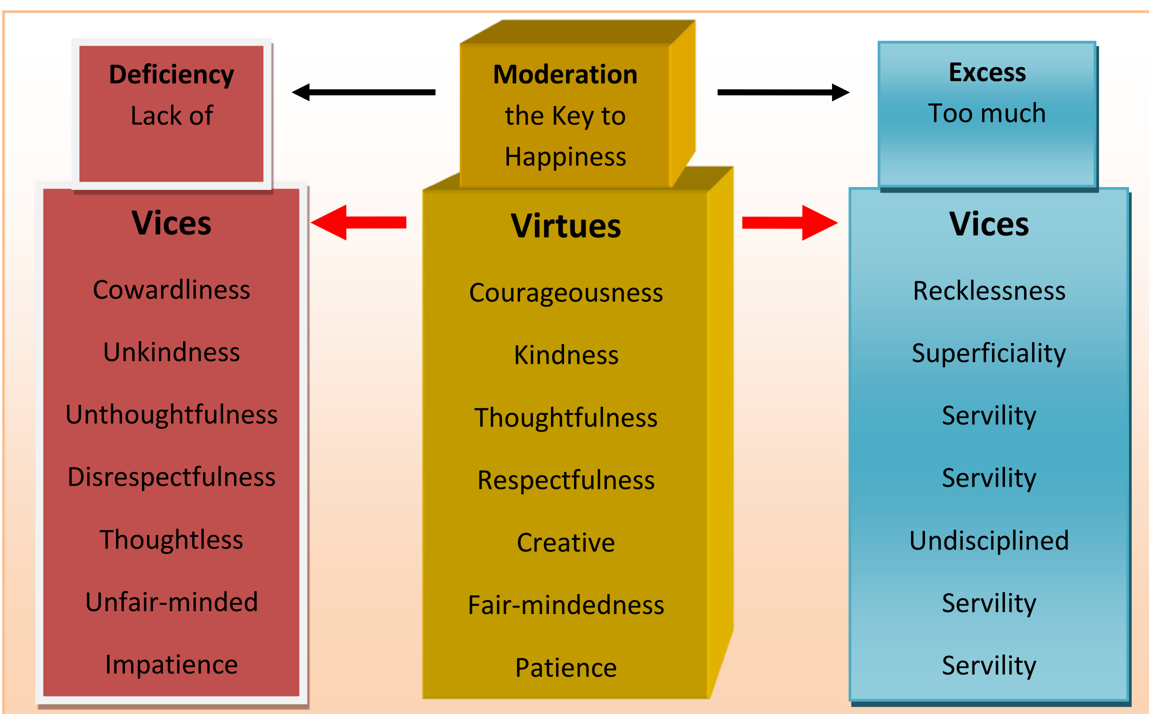
Figure 9 illustrates a stark contrast with **Fig. 8** and a deterioration of the demarcating orders of colors that improve drivers' abilities to distinguish between lanes. The problem with the lack of lane clarity is exacerbated during intense weather conditions and at night.

Ethics: Work Conditions, Beauty and Virtues

For Aristotle (384-322 BC) in order to live a moral and good life we must gain an appreciation of how power, wealth, health, pleasure, friendship, virtue and glory fit together properly. According to Aristotle, an **ethical virtue** has a disposition or tendency that is generally brought about by **habit** in order to have feelings that are appropriate (i.e., good as opposed to bad habits).

All virtues are conditions that are intermediate, i.e., in the middle of a pair of states that are vices as a result of either deficiency (e.g., a lack of patience) or excess (e.g., too much patience makes one servile, serving others excessively, and can promote laziness and other vices within others).

Fig. 10 Virtue Ethics: Golden Means in the Middle



In relation to technical skills, such as carpentry, Aristotle argues that virtues are no different insofar as any skilled laborer has knowledge about how to keep away from deficiencies and excesses in order to stay at an intermediate condition between deficiency and excess. For example, the skilled carpenter uses a moderate amount of nails, refraining from deficiency, which could cause the woodwork to fall apart, as well as an excessive amount of nails, which could be an eyesore or also compromise the structure of the production.

Thus, we have two claims put forth by Aristotle, which are: **(1)** all virtues are states residing between two vices; and **(2)** When a virtuous individual decides to act virtuously, she can be described as motivated to behave in a way that is intermediate between two opposing vices from which she refrains.

The second claim often involves confrontations with complications, especially if we think about one who chooses whether to go to a marriage ceremony or attend a meeting that occurs at the same time. Making the decision that coincides with choosing the intermediate between two extremes does not seem to be completely relevant in the latter sorts of cases.

In relation to engineering ethics of color we have already noted that the relevant virtues are: **thoughtfulness, kindness, respectfulness and fair-mindedness.** Again, the second claim may involve complications. For instance, it may be generous for one to respect the wishes of a fellow coworker with a colorful piece of art, say, on that individual's birthday, but such kindness of a coworker may lack thoughtfulness in respect to his or her officemate who detests the piece.

A gift for one may be an eyesore for another. Although this may appear to be unimportant, one should note that working conditions are very important because they involve what one experiences for hundreds of hours each year, and they influence us in many unforeseen ways.

Virtue ethics places its focus upon individuals' character traits and the virtues that make up each individual's character. Interestingly, an individual's character can be influenced by means of color and lighting.

We may have observed numerous amounts of unethical vices by those in authority in the Bangladeshi garment factory collapse. On April 24, 2013 over 1,200 people died in a building failure containing numerous garment factories. It seems unbelievable that the building with thousands of workers could collapse, which involved all sorts of oversights by engineers, inspectors, retailers, owners, citizens, and the press.

How far do the unethical vices extend? The building owner and others have been arrested and charged criminally, but what about the retailers who purchased the garments and overlooked conditions? Do the retailers bear any ethical responsibility? Does ethical responsibility stop once garments are made overseas?

The garment factory case may seem a bit farfetched, but what about not color striping a highway? Who has the ethical responsibility to drivers? Something as simple as using colors on a highway can save lives.

III. Engineering Ethics: Heat, Energy and Reducing Risks with Machinery

There is no doubt that the aesthetics of colors is one important aspect of our surroundings as professionals. Color is also elaborately interconnected with heat, energy, chemical, biological and other physical reactions with which we deal as engineers and architects.

For instance, the flames of fires with wood as fuel and candles' incandescent carbon particles emit radiation with **black-body temperatures** of up to 1,500° Celsius, which range from red to orange to yellow in order of their respective and increasing degrees of heat. Tungsten filament inside a light bulb has a temperature of approximately 2,200° C. Tungsten filament luminates yellows and whites.

Flashbulbs can reach approximately 4,000° C, which approach the white end of the color spectrum (Nassau, 1980). In general the order of colors in respect to temperatures of illuminating objects ranges from cooler to extremely hot in this sequence: red to orange to yellow to white, and finally to an extremely hot pale blue. Yet it is crucial to keep in mind the types of materials involved since some materials burn entirely different colors concerning their flames or smoke.

The backgrounds for heat are supported by the colors red through orange, called a **consonant action**. In other words, in a consonant action color may support or confirm a specific environment.

Conversely, a **compensated action** flies in the face of a specific environment. Again, looking at heat, a consonant environment would be an orange supporting warm as opposed to a blue or green compensatory role. Different types of industries can require work that is physically demanding, repetitive, or monotonous. Workers may be exposed to levels of heat, noise, odor, or high demands on vision. In fact, it is hard to imagine many jobs that do not place high demands on vision.

Correct environmental conditions improve human efficiency. Correct environments positively influence worker morale and safety. Conversely, poor worker environments decrease human efficiency, morale, and safety. Color and illumination for vision enhance industrial safety and environment.

Few would disagree that machines and equipment are meant to serve man! It can very well be critical that these machines and equipment have colors that serve, rather than hinder, functionality.

The improvement in the functionality of machines and equipment uses color to improve the perception of its critical or operating parts. Our eyes naturally focus on the brightest and most contrasting parts of the machinery. Proper colors on machineries keep eyes focused on critical parts used for mechanical operations. For example, gray colored machines may morally require a colored background.

Traditionally, without getting into different industry standards or Occupational Health and Safety Administration (OSHA) regulations, which are beyond the scope of this course, the basic safety colors are:

RED - for the identification of fire protection products, including extinguishers, fire alarms, and exit signs. Red can also be used on containers holding dangerous contents and often on kill switches on machinery. Perhaps it is most familiar as a traffic stop light.

ORANGE - which is used to designate danger. Orange may be used on exposed edges, gears, or other moving parts. The U.S. military uses orange on the nose of some of its aircraft.

YELLOW - which is used to designate caution. Yellow identifies physical hazards such as obstructions. Yellow is also the color of the middle traffic light, known as the caution light.

GREEN - which designates the basic color for safety. Typically, green is used to identify first-aid or health stations and is the "go" color for traffic signals.

BLUE - typically blue is used to identify electrical controls in some situations and repair areas on floors in some situations.

WHITE - designates a housekeeping area such as trash receptacles or drinking fountains.

BLACK-AND-WHITE STRIPING - is used on floors to designate traffic areas (Mahnke and Mahnke, 1993).

Fig. 11 Colors of Flames of Different Metals

Figure 11 illustrates the colors of flames of six different types of metals from the red of **strontium** and **lithium**, yellow of **sodium**, to the green color of the flame of **copper**, and the lilac color of **potassium**.

The colors result from the excitations of the electrons within the various metals and in combination with the temperatures of the flames. Photons are emitted as different colors of visible light as the electrons undergo a reduction of the amount of their energy levels. Elements produce different colors of flames. Moreover, the **colors of flames may be utilized in order to identify substances** that are unknown and burning.

Fig. 12 Texas A&M University Traditional Bonfire

Picture by Mikel Duke from Flickr.com

Figure 12 is a photograph of a traditional bonfire at Texas A & M University. You may remember during construction of another bonfire a disastrous collapse occurred, killing twelve people on November 18, 1999. **A color analysis of the fire's flames can determine the materials and temperatures** involved within the fire and thus illustrate that no materials burning hotter than wood were used.

Fig. 13 Bunsen Burner Flame Colorations Dependent upon Increasing Oxygen Levels

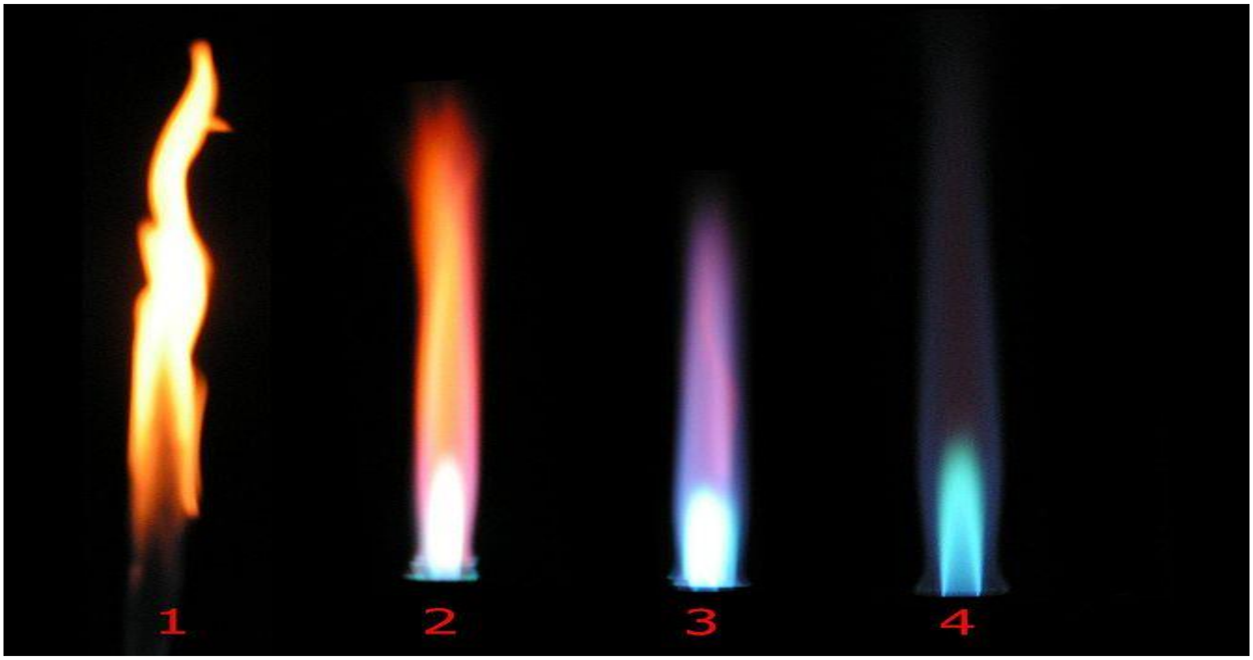


Figure 13 is a photograph of four flames with different colors emitted from a Bunsen burner. The first picture on the left shows a yellow "safety flame," which has a very low mixture of oxygen, and pictures two through four, respectively show increasing levels of oxygen. The heat of the flame increases with the increasing levels of oxygen and in the respective order of colors from red to orange to yellow and blue.

(Note: that the violet coloration in **Fig. 13** is a photographic phenomenon that is not produced as a result of the interrelations between combustion and increasing oxygen levels)

Fig. 14 Analysis of a Single Jet Flame (Methane CH4)

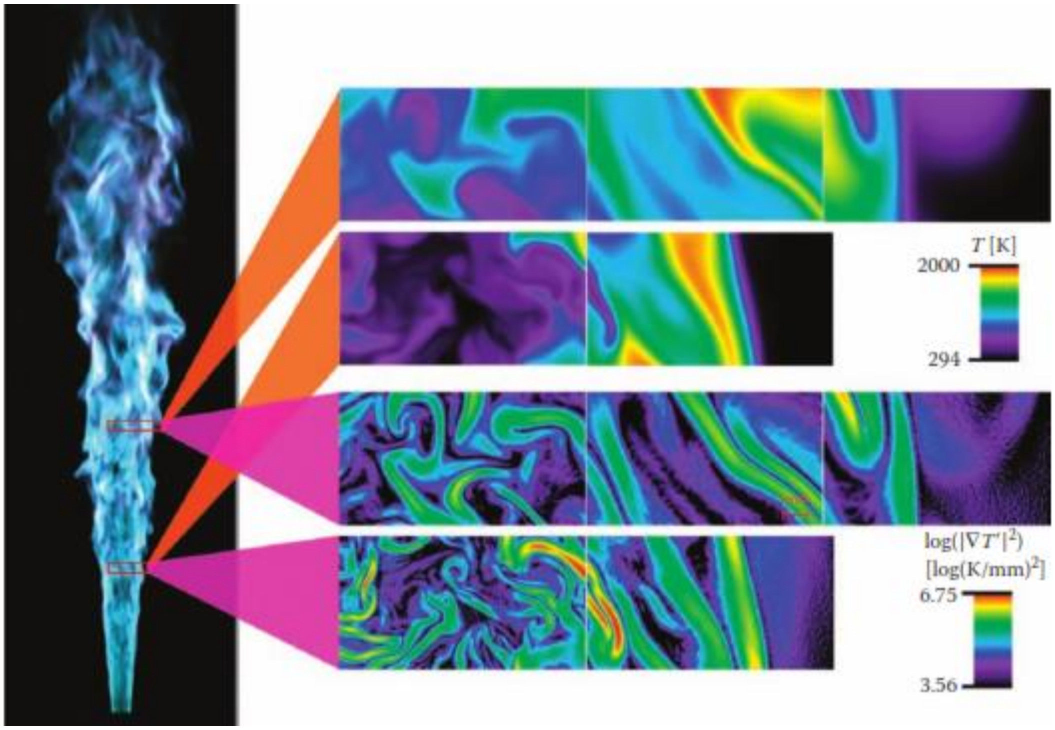


Figure 14 (Jarosinki & Veyssiere, 2009, 159) illustrates a conventional analysis of the emission of a flame during the combustion of a jet engine. As you can see color analysis is crucial both in respect to analyzing the flame itself as well as representing the measurements of various temperatures of each part of the flame at a particular time with various different colors.

Fig. 15 Blue and White Propane Torch Soldering Copper Piping

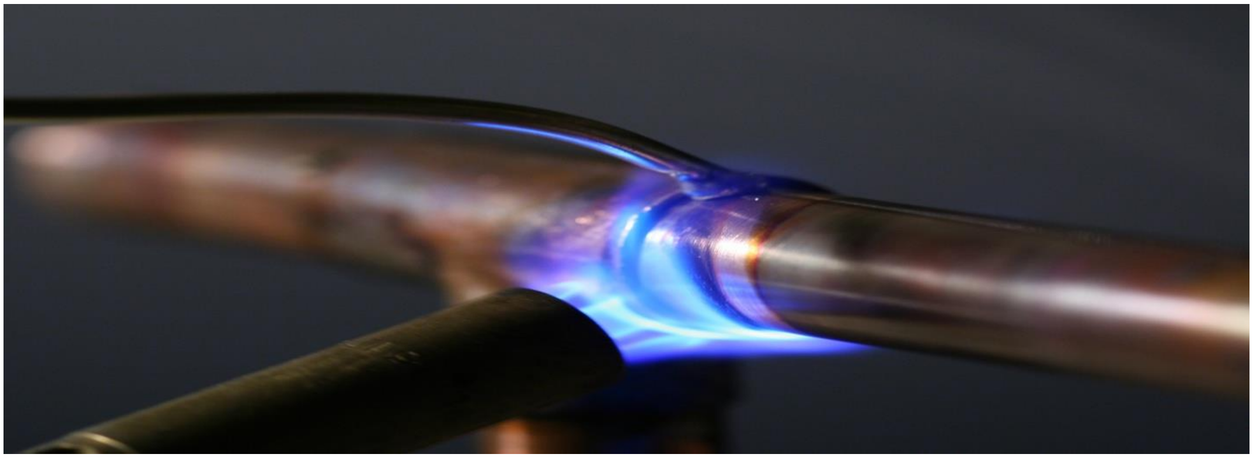
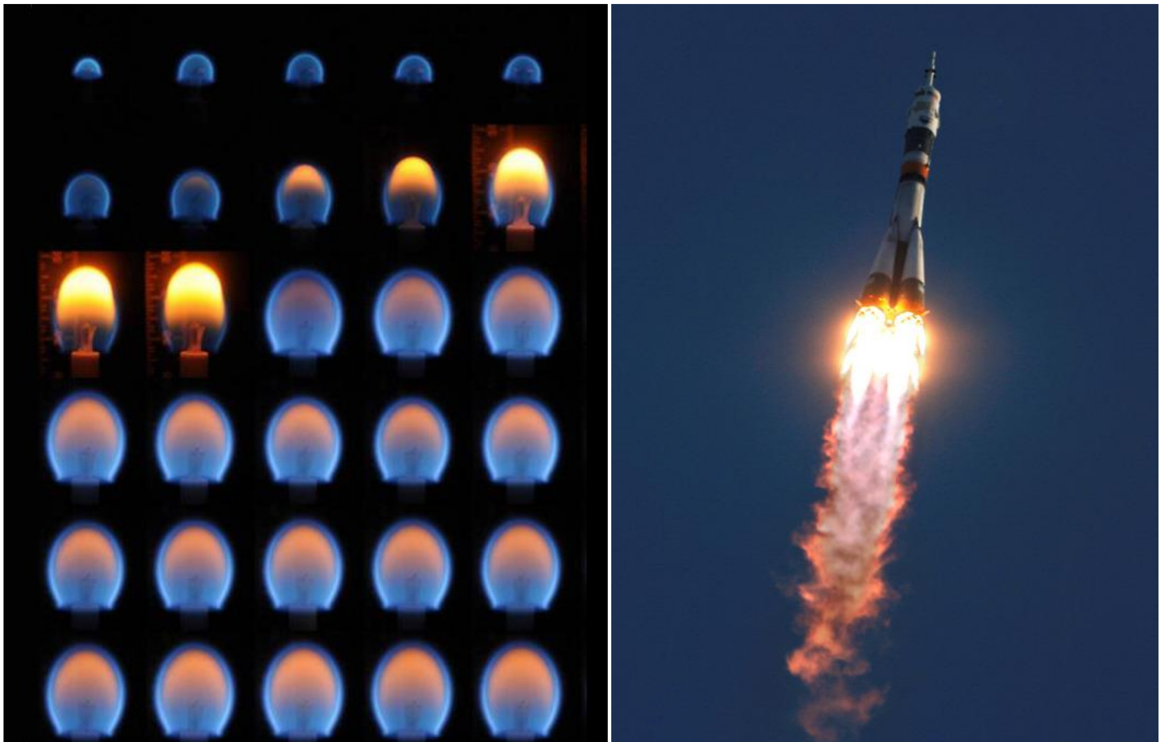


Figure 15 illustrates coppering piping being soldered by a propane torch, which reaches temperatures of 3,623 °F under ordinary conditions and can approach temperatures of up to 5,110 °F when the propane is fueled via pure oxygen.

Fig. 16 Flames in Zero or Microgravity and Flame Colorations of Rockets



NASA

Figure 16 depicts the formation of candle flames under the conditions of microgravity and the Soyuz TMA-8 launch on March, 30 2006. Colonel Chris Hadfield is accredited with the experimentation of a Burning and Suppression of Solids (BASS), which confirmed that within microgravity conditions, in which heat does not rise, flames burn in uniformly ovular or egg shapes.

House fires generally have lower burning temperatures and thus have mostly red flame colors and large amounts of thick black smoke since the fires generally burn with less oxygen inside the rooms.

Fig. 17 House fire with Red Flames and Black Smoke

Werner, 2012

Figure 17 illustrates a house that was struck by lightning in July 2012. Cooler flames are red and produce vast amount of black smoke because they occur as a result of the larger numbers of uncombusted carbon particles. Compare the color and heights of the flames of the A&M University bonfire in **Fig. 12** to the flames of this house fire in **Fig. 17**, which produces shorter redder flames and thicker clouds of black smoke.

There are multiple examples where we can distinguish heat and flames by means of their colorations. The colors give pertinent information with respect to our determinations of the types of fires that we consciously observe. So, the analysis of color is absolutely useful in respect to the analysis of temperatures, which concern aircraft engine explosions, jet afterburners, house fires and even toxic materials that burn.

Ethically speaking, such knowledge concerning the positive correlation between observer's conscious experiences of colors and the increasing hazards or danger of certain objects is absolutely necessary in certain settings for the purpose of reducing the risks of those hazards or danger that can maim or kill any of us who work within the vicinity of machinery or high temperatures.

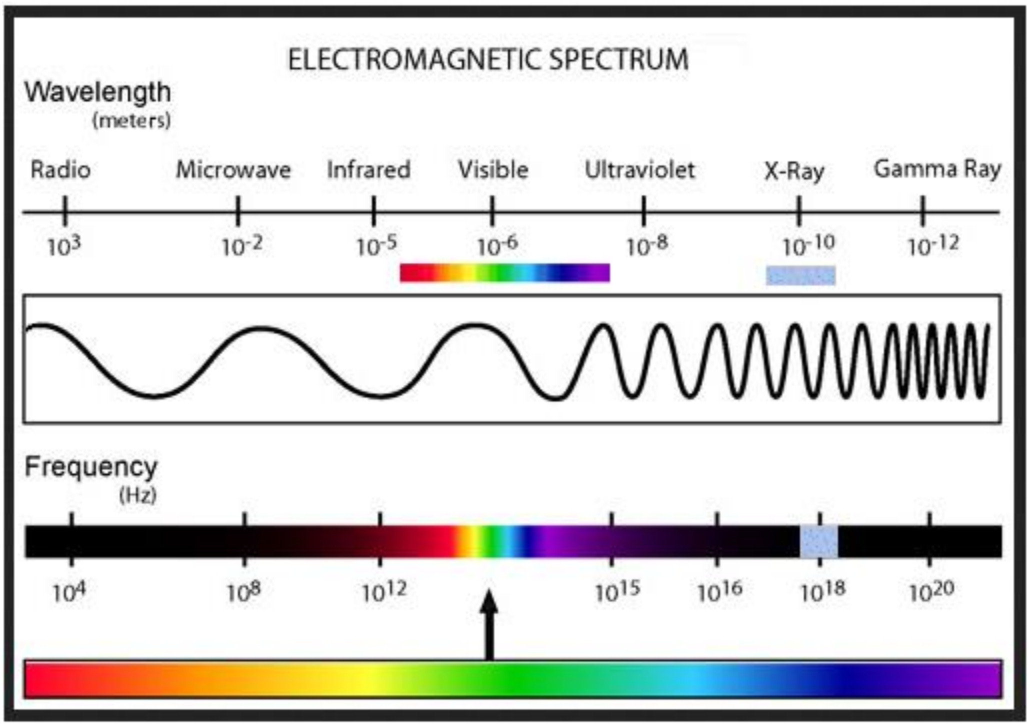
There is, indeed, a moral obligation for those who place workers in hazardous or dangerous locations to allow such locations to be optimum in order for observers to see the color of the light emitted by the hazard, be it machinery or accidental or upset conditions, which, in essence, allows observers to recognize from a distance hazards and danger.

Physics of Color Science

Colors, colored objects and color experiences influence our lives every single day. Physics employs the term "color" in various ways, which includes optics as one type of physical way of understanding color. Solid-state physics explores the origins of color that arise from crystallization processes.

Particle physics incorporates quarks within its levels of analysis, which bring electrical charges that are amazingly called blues, greens and reds, despite their total irrelevance to what physicists call the "actual colors" when they refer to a narrow portion of the electromagnetic spectrum called the *color or visible spectrum*, which is represented within **Figure 18**.

Fig. 18 Electromagnetic EM Spectrum



The color spectrum makes up approximately 1/80th of the EM spectrum. The EM spectrum is, of course, absolutely and physically necessary in order for color to arise as any sort of phenomenon from any level of analysis that ranges from conscious experiential accounts in psychology about colors to the biochemical reactions of the visual system and the measurements of colors in colorimetry.

Fig. 19 Heat Differences Concerning Fluorescent and Incandescent Lighting

Figure 19 illustrates that different colors of lighting have different temperatures, although the glass of the bulbs can be different colors and therefore change the color of the lighting without affecting the color temperature to the same degree. 2700° K is roughly 4400 °F, 3500 °K is about 5840 °F, and 5500 °K is approximately 9440 °F, which are very common temperature for average electric lamps within homes and offices.

Exactly how much light is needed for clear but comfortable vision continues to be questionable. Too much light fatigues eyes and too little light produces poor vision. Design of environmental space must consider visual efficiency and comfort.

Color in the environment is an important parameter. Typically, people prefer cool color temperature when illumination is intense and warmer color temperature when illumination is low. Color temperature describes the color of light from sources. (Mahnke & Mahnke, 1993). Ethically, engineers must be cognizant of these issues when dealing in environmental spaces.

IV. Engineering Ethics: Conscious Experience, Color and Computers

Why is the conscious experience of Color Important to Engineering? Humans often possess capabilities that they tend to take for granted until they are confronted with the loss of these abilities The abilities to form sensory perceptions and conscious experiences of color are examples of such capabilities, which provide most of us with an aspect of sensory perception and consciousness that is fundamental to the perceptible world within which we live.

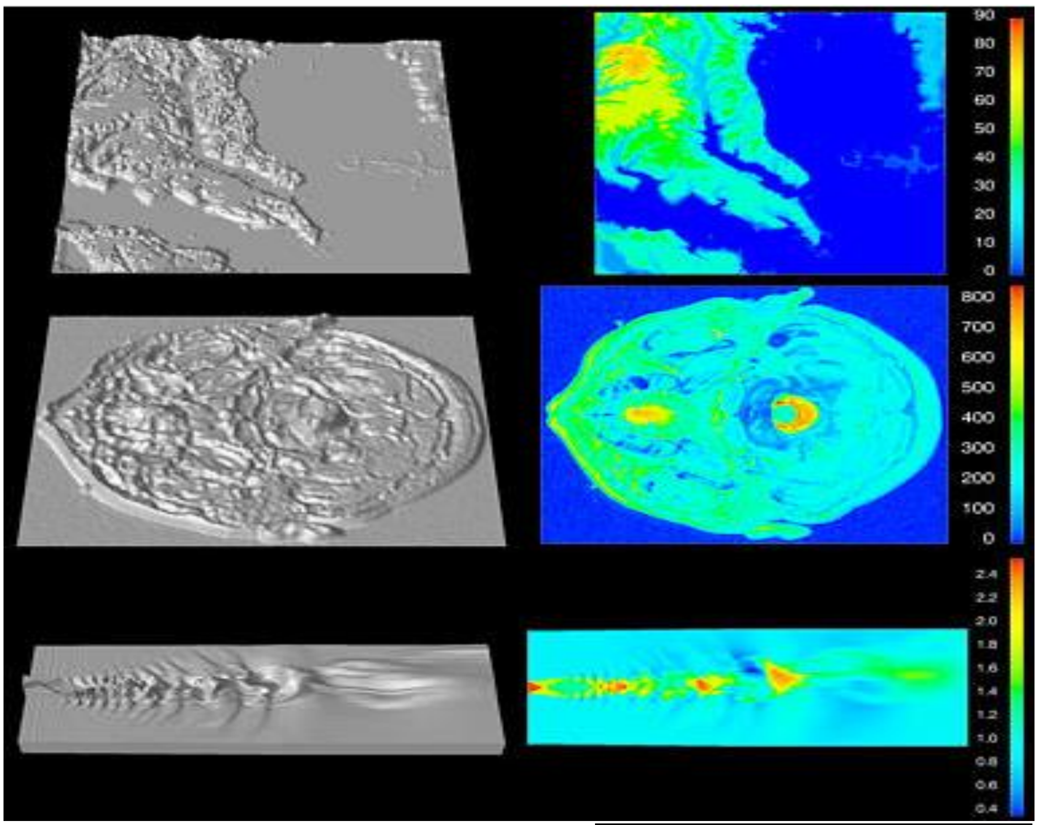
For example, you have probably heard of color blindness, and there are two very distinct types of color blindness: one concerns ordinary color blindness that generally results from one's shortage of a type of cone photoreceptor in the retina of the eyes; however, the other type of color blindness is far more serious and generally results from brain damage, say, from a automotive accident or brain tumor.

Color and Computer Technology

According to Rogowitz and Treinish (2013), engineers should be worried about color for the following reasons: There is a greater likelihood that points on rainbow color maps are inaccurate, hues that show quantitative changes present extremely precise data, saturation is more efficient for lower frequency changes, i.e., the change in brightness of the same colors, and luminance is good for high frequency change, which is an indicator of the overall brightness of the surface and involves numerous colors.

"Using examples from a wide range of application areas in science and engineering . . . uses of color can distort the meaning of the underlying data, and can lead the analyst to incorrect evaluations, conclusions or decisions."

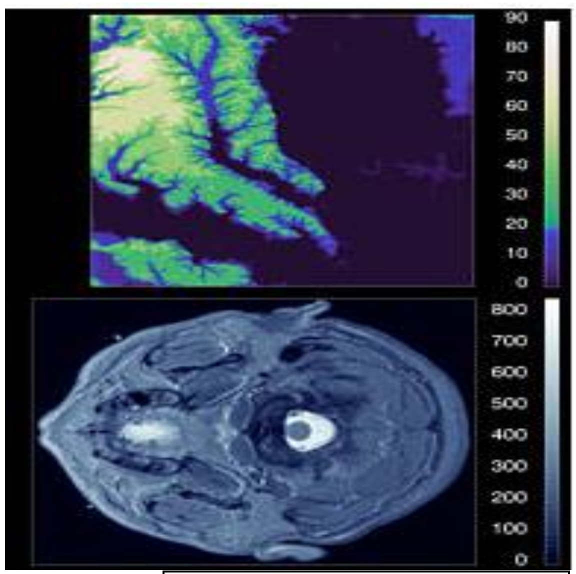
Fig. 20 Science and Engineering Data Represented within Colored and Uncolored Pictures



Rogowitz and Treinish, 2013

Fig. 20 illustrates three different examples of data being depicted pictorially with and without colors. The top two pictures are examples of the Chesapeake Bay area in Maryland and part of Virginia. Rogowitz and Treinish argue that the color representation on the right loses much of its complexity (i.e., its strength as a representation of the scientific data) regarding the transition from green to cyan (i.e., a bluish green). The second row depicts two images of MRIs, and the third row depicts the noise from a jet engine. So, there is an underlying importance in relation to graphic depictions of data with and without color that should be realized.

Fig. 21 Combining Depictions of Visual Data



Rogowitz & Treinish, 2013

It is also possible to combine the data from the left and right rows of **Fig. 20** in order to attain images that represent scientific data with greater accuracy, such as these combinations shown in **Fig. 21**. It is crucial for engineers to recognize the complexity of the data as well as the limitations of different types of representations of the data.

This creates an ethical dilemma for engineers: Just how accurate ought the data be?

Theoretic Systems and Philosophy of Color

Neuroscience and experimentation, which combine first-person accounts with fMRI data in innovative ways, raise many questions that are philosophic in essence, such as how first-person and third-person data (i.e., subjective and objective data) can best provide consistent explanations about what color is. There is no doubt that theory is necessary in order to guide research systematically via the creation of testable scientific hypotheses. Some of these hypotheses require the development of new experimental techniques.

Much philosophy of color is totally irrelevant to color science, however, since philosophy often functions at the level of the "metahypothesis" (i.e., hypotheses about hypotheses), which often lack the ability to be measured and are irrelevant in respect to observations (i.e., they may be presumed to be consistent with empirical observations based upon a lack of data concerning any contradictions). Metahypotheses involve formations of inquiries, which appear as logically-grounded and reasonable questions. However, such philosophic and investigative lines of inquiry are so perplexing to answer that philosophers do not know how to best phrase such lines of inquiry.

For instance, two of the main philosophic theories of color are strictly in opposition with one another. The first focuses on color as being merely an aspect of the subject, and the second theory focuses on color as merely an aspect of the objects, which are observed by the subject:

- Color is merely an aspect of consciousness, and objects that are external to subjects are not colored, i.e., Color Subjectivism.
- Color is only an attribute of external objects, such as reflection properties. So, external objects are colored, i.e., Color Realism.

Color subjectivism and objectivism (or color realism) are typically viewed as being counter-opposed to one another. They are popular theories, but they are typically irrelevant with respect to measurement in color science and colorimetry.

The importance of the considerations of color, i.e., as merely an aspect of consciousness versus color as an attribute of objects apart from the subject, is best viewed within a multitude of textbooks on the topic of sensation and perception. The latter types of psychology textbooks tend to support versions of color subjectivism whereas chemistry and physics textbooks, for instance, support color realism.

Stephen Palmer (1999) asserts that:

"{C}olor is a *psychological* property of our visual experiences when we look at objects and lights, not a *physical*

property of those objects or lights. . . . There may be *light* of different wavelengths independent of an observer, but there is no *color* independent of an observer, because color is a psychological phenomenon that arises only within an observer." (p. 95 & 97)

Obviously, Palmer's argument is insufficient to undoubtedly conclude that color is only a psychological property of one's visual experiences because one may just as well claim that there is no color independent of photons since color is a physical phenomenon which arises only with light.

Instead of supporting a form of subjectivism or objectivism about color, the authors suggest that color involves complex interrelations between observers, objects and the reflectances, absorptions and penetrations of light, which all provide necessary relations in order for color to arise. A combination of theories, if you will.

Light, for instance, **penetrates through the entire visual system** of the human being, going through the skull, **reflecting off of and scattering away from the visual system** and body of the observer. **Light also absorbs into the visual system and is emitted by the visual system itself** in very weak forms called **"biophotons."**

So, there really is no fine line that can be drawn, non-arbitrarily, that allows us to reasonably conclude where or when the subject has distinguishable boundaries and where or when the colored light is separate and distinct from the subject.

That is, **there are no temporal or spatial measurements that allow us to separate the colored light from the subject or colored light from the object**. What we are confronted with is, therefore, a set of extremely complex interrelations with lights, visual observations and various things that visually appear to us within our environments.

One reason for such great confusions about what color is (i.e., purely psychological versus purely physical) is that there is also great confusions about observation itself, such as whether observers observe the observed observations or whether there can be such things as meta-observations (i.e., **observations of observations**). Brant (2013) provides an illustration of this in the form of a cartoon designed by Daniel Dodd shown below in Figure **22**.

Yet another confusion involves the levels of observation, which are also present within the following cartoon, namely, the numerous **microscopic levels of observation** and **macroscopic levels of observation**.

Fig. 22 illustrates two colorful children observing a scientist who observes an object beneath a magnifying lens (Brant, 2013, 186). **The proximities of the observer and magnification levels of the observations affect the levels of the analysis and conclusions**

that are drawn. The same is the case for observations concerning light and its relationships with things that are viewed at multiple levels of observation from, for example, the atoms, which are not viewable with light, biological cells, tissues, organs and entire organisms.

Fig. 22 Observing the Observer and Levels of Observation and Analysis

Despite some overwhelming drawbacks concerning many philosophic-theoretic approaches to color, there is a need for certain sorts of philosophic investigations of color, namely, those which combine certain scientific investigations and aim to descriptively place trends within color science journals and experimentation within more valuable theoretic frameworks.

By valuable "theoretical frameworks" we mean those that can contribute to productions of testable scientific hypotheses and which provide explanations or descriptions that are consistent with the various multi-levels of analysis and multi-levels of observation, including, for instance, chemists' analyses of chemical reactions resulting from photons' impacts on different chemical elements that compose the eyes, the rest of the brain, and objects that reflect photons and change their chemical compositions.

Fig. 23 Color Illusion of Two identically Colored Dogs

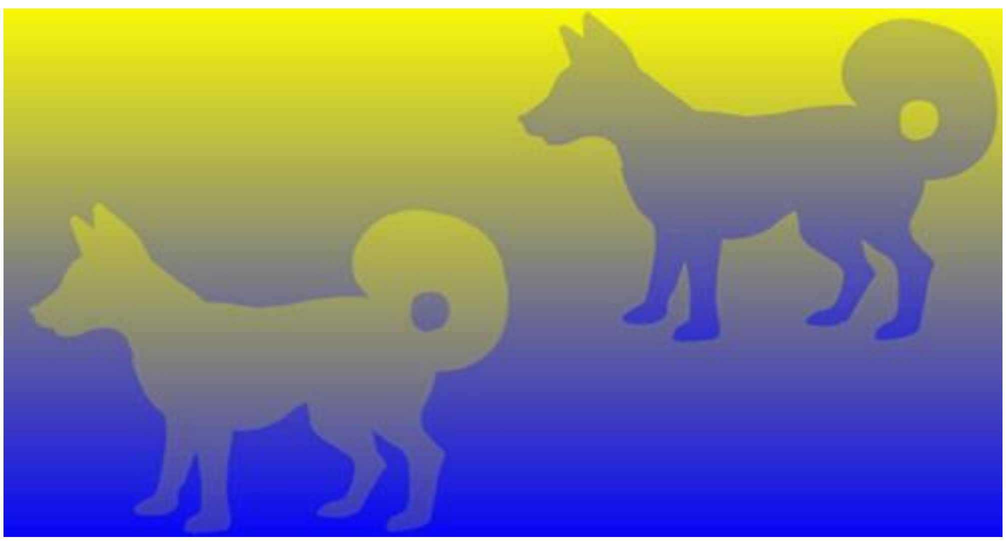


Figure 23 illustrates that two identically colored objects can easily appear different to the observer on the basis of the difference of the background of those objects. Both of the dogs are the same color, but have different backgrounds, which you may test via cutting the dogs out and comparing their colors without the background. http://brainden.com/color-illusions.htm

Additionally, background colors are important because optical illusions demonstrate that two colors that appear to be the same, as a result of their different backgrounds, are actually different colors.

Fig. 24 Color Illusion of Three identically Colored Squares

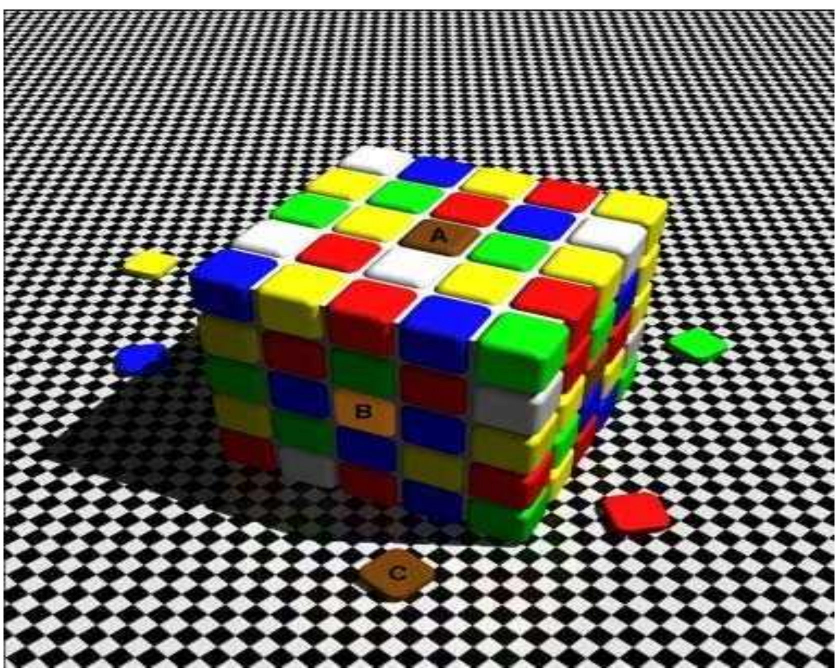
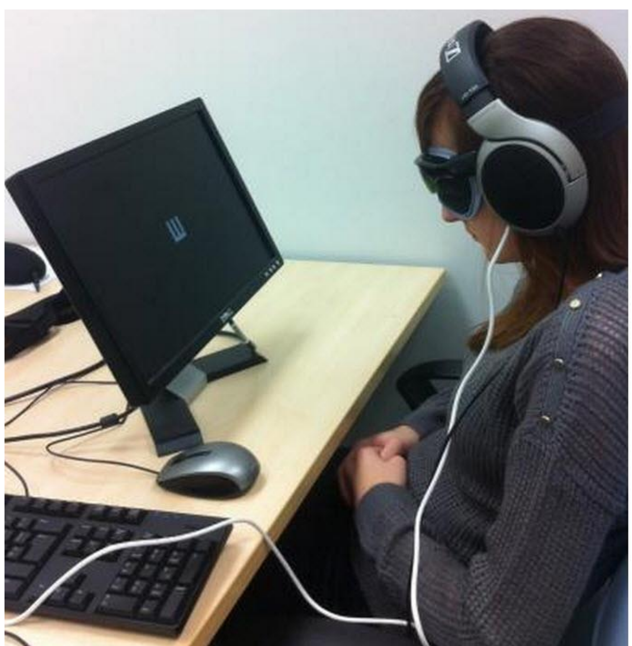


Figure 24 illustrates again that the background colors are crucial in order for us to make interpretations about whether colors are different or identical. In **Fig. 24** A, B, and C are identical colors. The fact that background colors must be taken into account with the color of the focal object is very important to consider, especially in relation to warning signs and other purposes concerning color and the reduction of risks.

Since engineers shall hold paramount the safety, health and welfare of the public, according to multiple ethics codes, engineers must be aware of these color illusions and guard against them.

Fig. 25 Audio-Video Technology for Seeing Based on Hearing



Haigh et al. (2013, 11)

Fig. 25 was taken from an article by Haigh et al. (2013), which describes sensory substitution devices that convert information from the lost visual sensory modality to the subject's remaining modality of hearing. The device actually encodes images that are captured via a camera and worn by each subject and converts the images into "soundscapes" in order for learned users to attain a form of visual and then auditory converted information from their surroundings. Finally, they undergo visual experiences once they learn to use the devices.

Interestingly, Haigh et al. (2013, 2) explain that: "One expert late-blind user ..., P.F., has pro- vided repeated, detailed descriptions of her experiences which, she claims, have gradually improved and become more like vision. Depth perception, smooth movement (as opposed to 1Hz "snap-shots") and even experience of colors emerged with continued use of the device for P.F., suggesting that her brain had been gradually adapting to more efficiently process this novel kind of auditory information (Ward and Meijer, 2010)."

The latter facts are interesting, concerning engineering ethics of color, because they illustrate that color can objectively emerge as a type of general information about the environmental surroundings of the subject, which can be converted into auditory information, and then experienced by subjects as colors!

The philosopher John Rawls (1971, 581) in his *Theory of Justice* asks us to image that "no one knows his place in society, his class position or social status, nor does anyone know his fortune in the distribution of natural assets and abilities, his intelligence, strength, and the like. I shall even assume that the parties do not know their conceptions of the good or their special psychological propensities. The principles of justice are chosen behind a veil of ignorance."

The idea that the principles of justice be chosen behind a "veil of ignorance" involves the idea that one should sympathize with all of those people who have the greatest disadvantages (i.e., whether they were born into extreme poverty or with extreme handicaps, such as blindness), especially since one can imagine being born into a poverty-stricken family or having to survive without the function of one's own vision, for instance.

The authors would argue that if the engineering technology is available for those with such disadvantages as blindness, then it is most fair and just to provide the disadvantaged with better opportunities through such technologies as the sensory substitution devices. This entails that such technology should be developed in the most cost-effective and efficient manners in order to provide the disabled with better chances in life, which increases certain liberties for them that had previously been prevented via their natural born physical limitations. Better life through engineering!

As with Aristotle's virtue ethics, **Fig. 5**, society at least appears to become a more just place when principles of fairness (e.g., giving the greatest benefit to the least advantaged in society) are incorporated, and there may be some usefulness in regard to thinking behind the veil of ignorance and thus thinking about society from the perspective of those with the most difficult challenges in life.

What is valuable concerning a philosophy of color is an ethics of color. Not only does it consider justice as fairness, but it portends notions of health and safety.

V. Color and Society

Fig. 26 Flag of the United States of America

We may divide society (e.g., American society) into numerous subsystems, which all utilize lighting and colors in overlapping and important ways. For example, the transportation system, education, law enforcement and military systems utilize colors and lighting respectively for the visibility of roads at night and for passengers in vehicles, for lighting that allows more optimal conditions for teaching and learning, and for uniforms, which illustrate officers' ranking orders according to police and military hierarchies.

Even our nation has its own symbolic colors within the specific order of red, white and blue, which is shown in **Fig. 26**. Our current 50 star flag was adopted on July 4th, 1960. Specifically, the flag colors are "Old Glory Red," white and "Old Glory Blue," which were formally specified in 1946 by the Journal of the Optical Society of

America (JOSA) and which formed the standards for cloth rather than printing.

Nationhood serves as a concept that involves the unification of individuals and various different social groups, peoples with different ethnicities, races and people of different colors, who all share the same symbol of representation by means of the colors of the national flag.

An ethics of color includes ethical principles, incorporates virtues and understandings of the relations of colors within the environment, especially environments that are created by humans and which involve multiple signals of types of dangers that catch our eyes with bright colorful hues (i.e., a hue is the gradation of a color that involves a description of how similar or different a color can be described in relation to red, yellow, green and blue).

An ethics of color also pays attention to aesthetics or the overall beauty of an environment, such as an office, which should involve interesting colors and designs so that workers are not merely exposed to office stimuli that promote boredom and indifference.

In the last chapter we saw the role of technological innovations, such as the sensory substitution device, which is beginning to play a fundamental role with respect to allowing the blind to see and experience colors. We also saw the crucial role of color analysis concerning the identification of heat, energy, waste materials (e.g., smoke) and other materials (e.g., copper, sodium and lithium that respectively give off green, yellow and red flames).

We have considered the importance of color in respect to the transportation system and civil engineering, allowing for lanes to be demarcated on bridges and roads. Moreover, we have considered the importance of color in regard to understand the brain through engineering combined with other multidisciplinary feats, such as computational neuroscience.

Each of the levels of observation are important from the microscopic chemical analyses of metals, dyes and microscopic analyses of biological cells and computations, such as in **Fig. 1**, to the observations made at ordinary observational levels (i.e., with the naked eyes) of different colored house and bonfires in **Fig. 12** and **17**, and finally to the observations that require statistics and understandings of groups or crowds and which are sociological in nature (e.g., behaviors of traffic and colored traffic lanes, colored safety equipment and even colored medicines).

All of the latter examples, levels of observation, and fields are fundamental for an engineering ethics of color, and they provide wide-ranging examples that impact our society and daily lives. From all of these wide-ranging perspectives colors matter to every one of us!

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