DOCUMENT RESUME

ED 397 835 IR 018 023

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TITLE	So Many Colors, So Many Choices: The Use of Color in Instructional Multimedia Products.
PUB DATE	96
NOTE	9p.; In: Proceedings of Selected Research and Development Presentations at the 1996 National Convention of the Association for Educational Communications and Technology (18th, Indianapolis, IN, 1996); see IR 017 960.
PUB TYPE	Reports - Descriptive (141) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Color; *Design Preferences; Guidelines; Instructional Design; *Instructional Effectiveness; Instructional Materials; *Multimedia Materials; Problems; *Screen Design (Computers); *Visual Perception; Visual Stimuli
IDENTIFIERS	Cognitive Load; Visual Displays

ABSTRACT

State-of-the-art computers being used today for instructional multimedia products have monitors capable of displaying millions of different colors. Designers are given virtually unlimited control over the factors that govern the display of these colors. This paper examines how color is displayed on computer monitors and interrelationships with how humans perceive color. Discussion also considers uses for color that are affective (adding aesthetic value), structural (text vs. backgrounds), and cognitive (highlighting, coding and layering to reduce cognitive load). Finally, the paper offers solutions to some of the problems inherent in the use of color and recommends guidelines for proper and effective use of color in instructional multimedia products. (Contains 37 references.) (AEF)

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Title:

So Many Colors, So Many Choices The Use of Color in Instructional Multimedia Products

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The average person can distinguish between 10,000 and 20,000 colors (Pettersson, 1993; Tufte, 1990). State-of-the-art computers being used today for instructional multimedia products have monitors capable of displaying different colors beyond these figures and well into the millions. Designers are given virtually unlimited control over the factors that govern the display of those colors. Not only can designers decide when and where to use color, but they can also determine the physical characteristics of the colors themselves. According to Keller and Burkman (1993), people have come to expect media products to have high-quality color, and indeed, most prefer instructional products that have color over those that do not. With the ready availability of color on today's computers, what is a designer supposed to do? There are so many colors, so many choices.

This paper first briefly examines how color is displayed on modern computer monitors and how humans perceive color. The three following sections consider three primary uses for color: affective, structural, and cognitive. The succeeding section discusses problems inherent to the use of color and offers some solutions. Finally, the paper concludes with recommendations for the proper and effective use of color in instructional multimedia products.

What Is Color, and How Does It Get on a Computer Monitor?

Color is a sensation and not a physical entity, according to Humphreys (1993). Murch (1983) maintained that the way we perceive color is the result of many factors: the capacity of the object in question to reflect and absorb certain wavelengths of light; the properties of the light source illuminating the object; the medium through which the light travels; the properties of the surrounding objects; the biochemical state of the eyes of the observer; and the observer's previous experience with the object or its colors. Although all of these factors are of concern to the designer, he or she usually has control over the first factor alone. That is, the designer can only specify what colors the monitor should display. Because of the intervening factors between the display and the eyes of the observer, the designer cannot control what colors the observer actually perceives.

As Norman (1990) pointed out, although color organization can be traced back to the ancient Greeks, it was Sir Isaac Newton who first brought us the now-familiar color wheel, the principles of which have become an underlying assumption for virtually every color model since. An example of one of these principles is that mixing together red, green, and blue paint produces a mixture approaching black. Producing new colors in this manner is referred to as an additive process and is the one with which most people are familiar. Unfortunately, color on a computer monitor is not accomplished by mixing colored pigment, but rather by mixing colored light. In this system, called subtractive, combining red, green, and blue light produces white. According to Norman, prior to the advent of color computers, very few people (theatre lighting designers being one exception) had the opportunity to combine colors using a subtractive process.

More specifically, a monitor's cathode ray tube produces an image when electrons strike the phosphorescent material lining the front interior of the glass. As Thorell and Smith (1990) described, the phosphors are arranged in triads of three primary colors: red, blue, and green. These phosphors are individually energized by three different electron beams and hence selectively lighted. Illumination of all three phosphors in a triad produces white, and illuminating none produces black. Stimulating different combinations in the triad produces secondary colors (for example, lighting the red and green phosphors results in yellow). By varying the intensity of the electron beams, a full spectrum of colors can thus be produced.

While color on a computer is constructed using red, green, and blue phosphors, humans commonly refer to color by three different interrelated components: hue, saturation, and lightness. Murch (1985) defined hue as the basic component of color (which depends on the specific wavelengths of light received), saturation as the purity of hue (which depends on the range of wavelengths received), and lightness as the amount of light reflected (which depends on the presence and amount of achromatic color—black, gray, and white). For example, "red" is a word used to describe hue; "pink" is a word used to describe saturation; and "dark" is a word used to describe lightness. So when someone describes an object as being "dark pink," for example, he or she has simultaneously used hue, saturation, and lightness in the description.

Samit (1983) contended that it is important for the designer to understand how a computer display's system works since colors on a computer are produced in the unfamiliar additive red-green-blue (RGB) system, but are perceived in the familiar hue-lightness-saturation (HLS) system. Murch (1983) described how the gap between these two color systems is bridged by most computer systems having an interface which allows the designer to manipulate controls for hue, lightness, and saturation directly and interactively.

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The Affective Role of Color

Many authors have argued that color adds a strong affective dimension to visual displays. Pettersson (1993) suggested that color enhances the perception of a visual message; Shneiderman (1987) concluded that color can add accents to an uninteresting display; Tufte (1990) maintained that color enlivens and informs the computer user; Dwyer and Lamberski (1983) noted that color makes displays attractive and emotionally appealing; and Dondis (1973) claimed that color is "the aesthetic frosting on the cake" (p. 50). More substantively, Samit (1983) reported that tests have indicated that viewers actually appear to feel they have a better understanding when images are displayed in color.

As Davidoff (1991) observed, there are particularly strongly held beliefs about emotional responses to color. For example, the color red is said to be make one feel warmer, to arouse one to action, to accelerate the passage of time, and to increase one's strength. On the other hand, Sharpe (1974) noted that blue (at the opposite end of the spectrum from red), is said to make one feel cooler, calmer, and more in control. Davidoff reported that there are very few well-documented and controlled studies that actually verify the effects of color on behavior. What is important for our purposes is that people *believe* that color affects them both emotionally and physically.

Structural Uses of Color

When designing screens for the computer-user interface, the designer must consider how the structure and the various functions of the interface will be communicated to the user (Brown, 1989; Faiola & DeBloois, 1988; Laurel, 1990; Pettersson, 1989; Shneiderman, 1987). Appropriate use of color can be used as an element in this communication process.

One such way in which color can be used structurally is in screen menu design. As an example, Shneiderman (1987) suggested showing all menu items in one color, the title in another color, the instructions in a third color, and error messages in yet a fourth color. When screen space is at a premium, he also recommended using dissimilar colors to distinguish close but logically distinct fields. Rambally and Rambally (1987) also suggested using different colors to separate prompts, commands, input/output (I/O) fields, and the like.

Using color for text is another option available to the designer. Both foreground and background colors need to be taken into account. Isaacs (1987) and Brown (19 9) both advised that the two colors should be chosen so that the greatest contrast in lightness is obtained. Keyes (1993) noted that since black and white have the maximum contrast in lightness, this combination has maximum visibility. Keyes added that instead of black, dark shades of green, blue, and violet could be used with only a small decrease in legibility. Assuming that the lightness/contrast rule is followed, Clausing and Schmitt (1989, 1990) demonstrated that the colors chosen have no significant effect on either reading rate or comprehension. Nevertheless, numerous authors have offered specific suggestions for which colors to use. Humphreys (1993) maintained that dark letters on a light background were more legible than the reverse, Pettersson (1989) proffered black or dark brown text on a light yellow background as being the most legible, Gillingham (1988) cited a Swedish study that claimed blue or green on white led to increased accuracy and higher subjective ratings, and Isaacs concluded that green text on a black background is the best choice.

Colored text can also be used to provide signals to the user. Marchionini (1988) suggested that color could be used in hypertext to indicate links. Cook and Kazlauskas (1993) recommended using two different colors in feedback after an incorrect response: one color to indicate what the user should do next and a different color to elaborate on why the user was incorrect. Keyes (1993) advocated using color for information types that are difficult to signal typographically, such as warnings, hints, user-entered information, cross-references, and section dividers.

Shneiderman (1987) suggested that when exceptional conditions or time-dependent information must be relayed, color can be used to attract the user's attention. Occasionally, there are times when the computer requires the user to attend to something unrelated to the user's current task. If the computer's need is not urgent, rather than having it forcibly and abruptly interrupt the user with a dialog box, Baecker and Small (1990) proposed having a less intrusive alerting icon that changes color to become progressively more red as it is ignored for an increasingly longer period of time. If time is more of the essence, Faiola and DeBloois (1988) advocated using highly saturated colors to attain a quick response.

When designing the structure of an interface with color, designers should also be aware that color can provide some overall physiological benefits. According to Tufte (1990), softening a bright white background with color calms video glare. Smith (1987) reported that the use of multicolor screens have reduced reports of visual stress or fatigue from users who had previously viewed information on black-and-white or single-color screens. Smith also contended that information on a multicolor screen can be perceived at a greater distance than a black-and-white version of the same information.

Cognitive Uses of Color

Color may also be useful for enhancing learning. Faiola and DeBloois (1988) claimed that color "can aid memory and enhance the understanding of information" (p. 16), Dwyer and Lamberski (1983) postulated that color can make instructional products "more effective in facilitating student achievement of specific kinds of learning objectives" (p. 304), Milheim and Lavix (1992) declared that "color can be used effectively . . . to aid in student learning" (p. 18), and Keyes (1993) averred that color can create "a visual layer that we separate perceptually" from other information (p. 646). Beyond the generalities, in what specific ways can color enhance learning? Numerous researchers and authors have suggested using color to highlight salient features, color code related bits of information, decrease the cognitive load, and simplify complex information.

Highlighting salient features. As Tufte (1990) noted, foremost among color's attributes is its ability to make things stand out, to draw the user's attention. Borrowing from classical cartography, Tufte noted that small spots of intense, saturated color can be used effectively to convey information by making it stand out from the rest of the illustration. Winn (1993) added that the highlighting color doesn't even have to correspond to the colors of things in the real world: using bright red to color the forearm of an athlete throwing a javelin, for example, is not meant to imply that the arm is in fact red, but rather to draw attention to the position of the arm. In a meta-analysis of the research on the use of color in visual displays, Christ (1975) concluded that using color to help users find and identify features is as much as 200% more effective than using size, brightness, or shape.

Color coding. Perhaps no instructional use of color has been as thoroughly considered and studied as color coding. Color coding is used constantly in everyday life, allowing us to readily associate particular messages with certain colors (Brown, 1989; Durrett & Trezona, 1982; Faiola & DeBloois, 1988; Rambally & Rambally, 1987). According to Durrett and Stimmel (1987), color affects the coding of information in human memory. They cited numerous studies in which color was used as an organizational and differentiating factor to help subjects recall and retrieve information. Somewhat surprisingly, Dwyer and Lamberski (1983) concluded that even if the colors chosen do not contribute to the message content, color can nevertheless still facilitate the retrieval of essential learning cues.

Christ (1984) offered one of the simplest ways to use color coding: identifying categorical information. The number of categories may be as few as two, such as in air traffic controller displays where one color is used to designate planes over a certain altitude and another color for planes below. Christ noted that although with training users can learn to increase the number of identifiable colors in a display, he recommended using fewer than ten. Others have advocated as few as three (Milheim & Lavix, 1992) to as many as eleven (Rambally & Rambally, 1987). Other applications of using color to categorize information include parsing the different parts of mathematical statements (Thorell & Smith, 1990), showing the nesting levels of a block-structured programming language (Shneiderman, 1987), and delineating the contours in an architectural drawing (Norman, 1990).

Color can also be used to order logically related data. In an example from chemistry, Thorell and Smith (1990) suggested using different saturations of the same color to code different concentration levels—high saturation to represent maximum concentration and desaturation for minimum levels. Similarly, in organizational charts, executive officers could be shown in saturated colors and divisions that report to them in desaturated values of the same colors. In an accounting environment, bright red could be used to indicate a payment extremely overdue and lighter shades to represent payments overdue by fewer days.

Color can also be used to code processes. Among their numerous examples, Thorell and Smith (1990) demonstrated using color coding to indicate the decomposition of a heated chemical compound, to represent the body's reactions to different amino acids, to signify the changes in stress loadings on solid objects, and to assist doctors in interpreting CAT scans.

Decreasing the cognitive load. Keyes (1993) postulated that we can use color to extend the cognitive limit by creating a visual layer separate from monochromatic typographic and spatial cues. Because color is perceived preattentively (automatically), less effort is required and the user can handle more information. In what is known as the neurophysiology of modularity, Davidoff (1991) asserted that in the visual system, color provides a secondary, pathway to the brain, parallel to that for other visual information. Adding credence to the hypothesis of modularity, Durrett and Stimmel (1987) related an experiment in which color was shown to be an extremely effective adjunct in learning nonsense syllables.

Cognitive load is closely allied to color coding. For example, since red is traditionally associated with stop, yellow with caution, and green with go (Brown, 1989; Durrett & Trezona, 1982; Faiola & DeBloois, 1988; Shneiderman, 1987), users do not have to learn new associations between these colors and their meanings. Thorell and Smith (1990) added that to most people, light colors give the impression of large sizes, light weights, tall heights, and close distances; dark colors give the opposite appearances. Accordingly, designers should be able to incorporate these associations with colors into their designs and expect users to respond accordingly.

Simplifying complex information. Color's propensity to make things stand out combined with its ability to code related items makes it an effective way to simplify complex information. Keyes (1993) argued that color simplifies by visually organizing and classifying information, clarifying both differences and relationships. As a simple example, Thorell and Smith (1990) described using colors to show the magnitude of change in an event: small changes in color (blue to green, for example) to signify small changes in magnitude and large changes in color (blue to orange) for large changes.

In addition to perspective, artists have long used color in three-dimensional drawings to separate the near from the far. Norman (1990) noted that grayer, desaturated colors appear farther away than more intense colors, giving the illusion of depth. Helping a user visualize three dimensions on the flatland of the screen can have profound learning effects. For example, Mayes, Kibby, and Anderson (1989) observed that significant advances were made in the understanding of molecular chemistry with the advent of computer graphic systems capable of displaying complex three-dimensional molecular structures using color to show grouping.

Problems and Solutions

As with any design element, color has certain potential problems associated with its use. Many authors have alerted us to the "color blindness" of some users (Brown, 1989; Durrett & Stimmel, 1987; Humphreys, 1993; Rambally & Rambally, 1987; Shneiderman, 1987; Thorell & Smith, 1990). As Thorell and Smith explained, our eyes have receptors called cones which fall into three groups according to their sensitivity to the primary colors of red, green, and blue. Deficient color vision occurs when any one or more of these three groups has insufficient sensitivity. True color blindness—being able to see only shades of gray—is exceedingly rare. Silverstein (1987) put the figure at less than 0.003% (3 people in 100,000). Partial color blindness is the total inability to perceive one of the three primary colors. Silverstein estimated that a little over 2% of the population have one or more forms of this deficiency. The most common color deficiency is not really color blindness, but rather color weakness. According to Silverstein, approximately 1% of the population is weak in perception of red and another 5% in perception of green. Consequently, about 8% of the population has some sort of color deficiency. Depending on the type, color deficiencies are 10 to 100 times more prevalent in males than in females. It is important to note that all color deficiencies affect only the perception of different hues—all color-deficient individuals can still perceive differences in lightness and saturation.

There are several ways in which the designer can compensate for color deficiencies. As has already been noted in several examples, instead of using different hues, the designer can use either different saturations or different levels of lightness to represent different entities. When different hues are deemed necessary, however, Keyes (1993) recommended varying the individual saturations so that the contrast is accentuated (for example, instead of using bright red and bright green, consider using bright red and pale green—even the totally color blind will be able to perceive the difference). Another alternative is to use what is called "redundant cueing." Instead of using only color to signify differences, Durrett and Trezona (1982), for example, suggested using shapes or labels in addition to colors.

Because of the physiological structure of our eyes, certain colors create certain problems. One limitation outlined by Humphreys (1993) is that the lens of the eye is not color corrected, thereby causing pure, saturated colors at the same distance to appear to be at different distances. Along these same lines, Samit (1983) explained how the eye cannot precisely focus on all colors together. For instance, since the eye cannot focus on red and blue simultaneously, the muscles will be forced to focus alternately on one color and then by the other, with resulting eyestrain. Samit also noted that because the center of the retina is nearly devoid of blue receptors (even in people with normal color vision), small blue objects virtually disappear when we try to focus on them. Two solutions present themselves immediately: avoid pure, saturated colors at opposite ends of the spectrum (Durrett & Trezona, 1982), and don't use blue for fine lines and text (Humphreys).

Another problem with using color is that not everyone responds to color in the same way. There are cultural, gender, age, and occupational differences. For example, Thorell and Smith (1990) pointed out that in Japan green implies youth and energy, but in France it connotes criminality. In the United States, yellow stands for caution and cowardice, while it signifies happiness and prosperity in Egypt. Several studies have attempted to show that males and females differ in their color preferences and responses (Davidoff, 1991; Krishna, 1972; Sharpe, 1974). Sharpe claimed that older people prefer bright primary colors (perhaps because color acuity declines with age), while Durrett and Stimmel (1987) found that children are not able to utilize color coding as quickly as adults can. While blue represents corporate reliability to financial managers (as in "Big Blue" [IBM]), Thorell and Smith pointed out that blue represents death to health care professionals (as in "code blue"); red means danger to process control engineers, but healthy to health care professionals.

Again, the solution is for the designer to know the audience and to conduct prototyping and user-acceptance tests (Brown, 1989).

Using colors inappropriately or using too many colors can create what Albers called "1 + 1 = 3 or more" (as cited in Tufte, 1990, p. 53). That is, certain uses and combinations of colors can create unintentional artifacts or visual "noise" (Tufte, 1989). We have all seen, for example, the kind of optical illusion where the image seems to literally vibrate because of the intensity of the colors. Tufte's (1989) solution was to use the colors found in nature, since they offer some measure of a accepted visual harmony.

Recommendations

Color is undeniably a part of our lives. We use colors to help identify, categorize, and locate things. We use color terms to express emotions ("feeling blue," "in the pink," "green with envy," and "yellow-bellied"), to ascribe motives ("yellow journalism," "pinko," "red herring," and "true blue"), to denote financial states ("in the red" and "in the black"), to describe qualities ("purple prose," "greener pastures," and "red letter day"), to compare things ("more [of something] than there are colors in the rainbow," "black and white," and "shades of gray"), to express actions ("color my opinion" and "looking at the world through rose-colored glasses"), and to advertise ("Coca-Cola red," "Pepto-Bismol pink," and "Kodak yellow"). It seems only appropriate that designers should take advantage of what color has to offer in both the affective and cognitive domains.

In order to incorporate color aesthetically and effectively into instructional multimedia products, designers have at their disposal a wealth of information from the fields of graphic design, fine arts, psychology, behavioral science, physiology, optics, cognitive science, semiotics, linguistics, cartography, human factors engineering, ergonomics, military science, architecture, and anthropology. Knowing how color is produced and perceived should help the designer better understand the contributions (and detriments) that color can offer. Although good instruction can be accomplished without using any color whatsoever, color may provide an additional factor in human encoding processes.

Because computers now have millions of colors available, there is a tendency for some designers to overdo it. The best advice in this regard came from Tufte (1990): "Above all, do no harm" (p. 81). Too much color can be distracting, and has even been shown to degrade performance on memory and recognition tasks (Christ, 1975, 1984; Dwyer & Lamberski, 1983). Screen designers would do well to follow the lead of graphic artists who design in black, white, and shades of gray before they ever add color. This practice enables them to judge overall balance, harmony, and clarity (and discover any potential problems for the color deficient).

The full range of uses for color has yet to be fully explored. Some of what Salomon (1990) called "new uses for color" (p. 269) hold promise for instructional products. As an example, Salomon explained how a document's icon on the desktop could be colored to indicate its age—yellow for new documents, through progressively duller shades of brown for older documents. Color could also be used to provide additional functional information to the user. Most computer operating systems today use some sort of icon to indicate that the computer is currently busy—the wristwatch on the Macintosh and the hourglass in Windows are two such examples. When the user might be interested in knowing more precisely the internal workings of the computer, Baecker and Small (1990) recommended having an icon that is blue to indicate that the current action is totally CPU-bound, yellow to indicate totally I/O-bound, and colors in between blue and yellow to indicate more balanced processes. Color has also started to play a role in the implementation of so-called guides. The Macintosh's System 7.5, for example, uses color dynamically to highlight the next step in a process. Color could also be used to help young users locate hidden or secret information in a game-like environment. By having the cursor change color as it is moved about the screen, children could be told when they are "getting hot" (red) or when they are "getting cold" (blue).

Much has been written about the instructional use of color. However, authors disagree on advice and their studies often contradict one another. It is clear that additional research is necessary. Durrett and Stimmel (1987) noted the following irony:

> The amount of research done on color as a variable in learning, attention, and coding reached a peak in the late 1960s and early 1970s, declined slightly during the 1970s, and declined dramatically between the late 1970s and the present. This is paradoxical because the use of color in the media of instruction and the potentials for use of color in instruction has grown dramatically. (p. 249)

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