Color Research and Its Application to the Design of Instructional Materials

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This paper is divided into three major sections: Color as Seen—Physiological; Color as Seen—Psychological; and Color and Learning. The first section deals with color adaptations and the effects of color on acuity and relates these to the design of instructional materials. The second section covers color meanings and preferences, as well as color harmony and the relationships of these factors to the design of instructional materials. The third section provides an overview of research on color and learning. It includes the effects of color on attention, search tasks, other objective and non-objective measures of learning, and the use of color for cathode ray tube (CRT) displays. Although the measurable effects of color may be slight, colored materials are preferred and they are used almost universally. Therefore, designers of instructional materials need to use color wisely by paying attention to the physiological and psychological effects of color and the effect of color on learning.

□ Color is used almost universally in the production of instructional materials, such as overhead transparencies, slides and filmstrips, motion pictures, and video programs. Printed instructional materials and computer-assisted instruction lessons are almost always produced in color. However, this attribute is often used without due consideration for what is known about it from research and practice. A great deal has been written about color from many points of view. For the purposes of this paper, the writers have chosen three categories that are relevant to instructional technology: color as seen—physiological; color as seen—psychological; and color and learning.

Information in these three categories will be discussed and suggestions made for effective use of color in the design and production of instructional materials. Articles on color are sometimes difficult to interpret because of the nomenclature employed by different writers to describe colors. In order to avoid confusion, it is necessary to define terms carefully. The following definitions used in this paper are those commonly used to describe the attributes of color:

- *Hue*—is the common name for a color, such as red, yellow, green, or blue.
- *Value or brightness*—is the lightness or darkness of a color measured by the amount of light the sample reflects or transmits.
- *Saturation or chroma*—is the degree of pure color in the sample, measured by the amount of redness, blueness, greenness, and so forth.

COLOR AS SEEN—PHYSIOLOGICAL

Color is almost never seen as it is (Albers, 1963). People have norms for colors of familiar objects that are independent of the texture of a surface or the lighting that falls upon a surface. The color of an object is influenced by our expectations; that is, when we look at a familiar object we see the color we expect to see. For example, we tend to see snow as white whether it is reflecting warm evening sunlight or the light from open blue sky. A ripe orange looks the same color whether it is in direct light or shaded from direct light.

The context in which a color is viewed is also a significant factor. Hue is changeable depending on other hues seen simultaneously or sequentially (Bloomer, 1976; Evans, 1943). This phenomenon is directly related to the way our eyes adapt to color. There are three types of adaptation: general, local, and lateral.

General Adaptation

General adaptation occurs when a person moves from a light room to a dark room or vice versa. In either case it takes the eyes a few seconds to adapt to the new conditions. It also occurs when moving from outdoor to indoor light or from indoor to outdoor light. Outdoor daylight is bluer than indoor incandescent lighting. As one moves from incandescent to daylight conditions, the eye becomes more sensitive to yellow light. This results in a neutral surface; that is, white or gray, continuing to be seen as neutral even though it is illuminated by bluish light. Similarly when moving from daylight to indoor conditions, the eye becomes more sensitive to blue and again, a white or gray surface is seen as neutral. The color of objects appears to be constant regardless of the energy distribution of the light source (Evans, 1943).

Local Adaptation

Local adaptation is demonstrated by afterimages. When the eye is fixed on any colored target there is a readjustment of the sensitivity of the eye to color in and around the target area. This adaptation does not affect the color being viewed, but does affect the next color viewed which is influenced in the direction of the complementary color of the target. For example, if a person looks at a red target for a few seconds and then looks at a neutral surface, a cyan image of the target will appear. The afterimage is always the complementary color of the object viewed. Similarly, if a person looks at a red target for a few seconds and then looks at a yellow-green area, that area appears more greenish than normal because the yellow-green is modified by the cyan afterimage. These effects are most pronounced when the target color is highly saturated (Evans, 1943).

Lateral Adaptation

Lateral adaptation refers to the effects that are created when two colors are viewed simultaneously. The perception of any color is influenced by the value, hue, and saturation of the color adjacent to or surrounding it. Gray on black looks lighter than gray on white and, conversely, gray on white looks darker than gray on black. Any color will tend to look lighter next to a darker color and darker when it is next to a lighter color (Bloomer, 1976). Two hues that are adjacent, or nearly adjacent, to each other on the color wheel will tend to shift away from each other when viewed side by side. For example, if yellow and orange are viewed next to each other the yellow will look slightly greenish and the orange will look slightly reddish (Bloomer, 1976; Evans, 1943; Pitt & Winter, 1974). Any color will look more saturated on a background of a complementary hue or gray than it will on a background of a hue that is adjacent on the color wheel. For example, red on cyan looks more saturated than red on yellow. The saturation of a color will be maximized when it is seen against a gray of the same value (Evans, 1943).

Arousal

Another physiological aspect of color is its capacity to arouse or stimulate a person. The effects are usually measured by galvanic skin response (GSR). Wilson (1966) reported higher

GSR measurements for red as opposed to green, and Nourse and Welsh (1971) reported higher GSR readings for violet than green. Using 24 male college students as subjects and saturated samples of red, yellow, green, and blue as stimulus materials, Jacobs and Hustmyer (1974) found that red was significantly more arousing than either yellow or blue, and green more than blue. Using 40 undergraduate students as subjects, Jacobs and Suess (1975) found that red and yellow resulted in higher anxiety state scores than blue or green when measured by the State-Trait Anxiety Inventory. Bloomer (1976) also reported that red increases heart rate. There appears to be some evidence that spectral extremes, especially red, cause greater arousal than mid-spectral colors. This may relate to the fact that wavelengths at the extremes of the spectrum, such as red and violet, focus at different points in the eye than wavelengths at the middle of the spectrum. This focusing differential also causes reds to appear to advance and blues to recede (Bloomer, 1976; Evans, 1943).

Acuity

Acuity is defined as the keenness of perception. Acuity is greater for a person who can read the 20/20 line on an eye chart than a person who can only read the 20/30 line. In a study using eight females and eight males from each grade from 2 to 12, Kelton, Holmes, and Pollack (1978) found that acuity decreases in proportion to the distance from the yellow locus of the spectrum. Sanner (1974) also found that it was generally true that acuity was better for colors in the middle of the spectrum than for colors at the ends of the spectrum. When legibility was critical, Snowberg (1973) found the following ranking of background colors from best to worst were: (1) white, (2) yellow, (3) green, (4) red, (5) blue.

A study by Start (1989) used undergraduate students as subjects and colored slides with colored images on a black background as stimuli. White and three values (brightness) each of blue, green, red, and yellow were used. Acuity was reported to be greatest for white, followed by the three values of yellow. It is probable that value was a more important variable than hue. The generalization in the summary of findings that "the best colors to be used in designing projected visuals considering color and time interactions are white and middle yellow" is overstated.

Richards and Macklin (1971) reported that lettering is more legible with a neutral background than with colored backgrounds of the same transmittance, and color coding is detrimental to comprehension when the light loss because of colored backgrounds affects legibility. G.H. Robinson (1975) indicated that brightness contrast is the most critical factor in legibility and that the effect of color is not significant assuming proper lettering size and projection standards are met.

Recent studies by Gustin (1990) and Cuttill (1991) provide additional evidence that acuity is greater for colors in the middle of the spectrum. They used white lettering on colored backgrounds as stimulus materials. Gustin used projected slides and Cuttill used images on a cathode ray tube (CRT). Gustin found that, across three background densities, yellow and cyan were significantly better in facilitating legibility than red or blue, and green was significantly better than blue. It should be noted that the blue was toward the violet end of the spectrum. Cuttill's results indicated that yellow, magenta, and blue provided the best legibility. Although the hues used in the two studies were not quite the same, the variation would not seem to be great enough to cause the differences in the results. Replication of the studies might shed light on the causes of the differences (Pett, 1994).

It must be remembered that about 7% of males and .5% of females are color deficient to some extent. Color-deficient persons tend to confuse red and green with yellow (Chen, 1971). Reds and greens of similar value and all colors of high value tend to cause confusion for persons who are color deficient (Richards & Macklin, 1971). Increasing hue contrast tends to improve discrimination. That is, using colors that are opposite, or nearly opposite, on the color wheel provide better discrimination than using colors that are adjacent. However, the most important cue is value contrast. A value contrast of 30% or more increases color deficient viewers' abilities to discriminate (Chen, 1971).

In summary, general, local, and lateral adaptations affect the way we see colors and this is predictable. There is some evidence that colors at the ends of the spectrum (e.g., red and violet) have greater arousal effects than colors in the middle of the spectrum (e.g., green and cyan). Conversely, acuity is greater for colors that are in the middle of the spectrum. For color-deficient persons value contrast is essential if acuity is to be optimized.

COLOR AS SEEN—PSYCHOLOGICAL

The psychological aspects of color of interest to instructional designers can be divided into three broad areas: preference, meaning, and harmony.

Preference

The earliest study on color preference was published in 1894 and in the subsequent half century about 50 other color preference studies were reported. In 1941, Eysenck conducted two experiments using mostly university students, a few professional persons, and one or two artists as subjects. They were equally divided between males and females. Stimulus materials consisted of ten 3½ × 5½-inch colored papers. Six were saturated samples of blue, red, green, violet, orange, and yellow. Three were tints (high values) of green, red, orange, and one was a shade (low value) of yellow. The selected order of preference was: (1) blue, (2) red, (3) green, (4) violet, (5) orange, (6) yellow. This selection agreed with the average rankings of color preference among 21,060 subjects reported in earlier investigations. The order was the same for all races and for men and women with one exception. Men chose orange over yellow whereas women chose yellow over orange. In 1963 Burnham, Hanes, and Bartleson reported that a compilation of many studies indicated the same general order of color preference reported by Eysenck and no significant differences between men and women or between subjects of different races.

Mather, Stare, and Breinin (1971) studied a geriatric population with a mean age of 74.4 years and found that blue was most preferred and yellow least preferred by both males and females. Females had a slight preference for green as compared to red, and males had a slight preference for red. Sinofsky and Knirk (1981) reported that color preference generally appears to change from warm (e.g., red and yellow) to cool (e.g., green and blue) as age increases. The finding by Mather, Stare, and Breinin (1971) that older men prefer red over green is at variance with this generalization.

In most of the early studies, the attributes of saturation and value were not adequately considered. However, when these factors are taken into account in subsequent studies, findings show preferences related to age and sex. Child, Hanson, and Hornbeck (1968) used pairs of 5½ × 8½-inch Munsell color papers on a black background and noted preferences of 1,100 subjects who ranged from grades one to twelve. The colors represented six hues, four saturation levels, and four values. Results showed a consistent preference for cool colors such as blue and green. There was a general preference, that decreased from fourth grade to twelfth, for high-chroma, more saturated, colors. This decrease was much greater for girls than for boys. Also, in this study girls of all ages preferred higher value, brighter, colors as compared to boys (Child, et al., 1968).

Guilford (1934) reported that hue determines the preference or affective value to the extent of about 67% for women and 16% for men. Value or brightness determines affective value about 20% for women and 5% for men, and saturation determines affective value about 5% for women and 13% for men. The high-chroma, more saturated, colors were preferred.

Schaie (1966) pointed out that color preferences vary from individual to individual and relate to personality. C. Robinson (1975) reported a significant relationship between the personality traits of introversion/extroversion and color preference. Extroverts chose the warm colors, red and yellow, and introverts selected the cool colors, blue and green. No interpretation of the results was given.

In summary, although there is evidence that color preferences change with age and are influenced by cultural differences and individual characteristics, the overall results show that cool colors rate highest. However, it is difficult to make direct comparisons between these studies because methodologies have varied widely and, in most cases, the colors used have not been adequately specified. The study by Child et al. (1968) which uses precise Munsell color designations is an exception. In addition, it is important to recognize the fact that color preferences, as measured in most controlled research studies, may not be related to the preferences that would be indicated in real-life conditions where colors are seen in a context in combination with other colors.

Gustin's (1990) study measured viewer preference for color of backgrounds of projected color slides with white letters on colored backgrounds. The order of preference was: (1) cyan, (2) blue, (3) green, (4) yellow, (5) magenta, and (6) red. Colors in the middle of the color spectrum were generally preferred. A follow-up study by Cuttill (1991) used approximately the same colors, but the images were viewed on a CRT. The order of preference was: (1) blue, (2) cyan, (3) magenta, (4) red, (5) green, (6) yellow. Again, blue and cyan were the two most preferred colors. There is no clear reason why the order of preference of the other colors should vary in the two studies. It may have been due to slight differences in the projected colors and those viewed on a CRT.

Meaning

Colors seem to have generally accepted meanings. There is agreement among adults that red, orange, and yellow are warm colors, while green and blue are cool colors (Burnham, et al., 1963). This association seems to be independent of value or saturation, and is apparently learned (Wright, 1962). In a study of associations between temperature and color choices, Morgan, Goodson, and Jones (1975) used six boys and six girls, in three age groups of 6, 12, and 18 years old, as subjects. Subjects placed their fingers on a metal tube that could be controlled to 4, 23, 35, or 45 degrees centigrade. Subjects were shown color choice slides consisting of four colored squares and asked to state which of the four colors—red, yellow, green, or blue—reminded them of the temperature felt. No indication of the chroma or value of the colored squares was given. Eighteen-year-olds made the conventional associations: red is hot, yellow is warm, green is cool, and blue is cold. Twelve-year-olds associated only red with hot, while six-year-olds made chance associations.

There is also a general consensus that dark colors appear dull, somber, and heavy while light colors appear airy and less heavy (Burnham, et al., 1963; Evans, 1943). The results from a study, using 200 college-aged adults as subjects, suggest that yellow tends to be associated with comedy or happiness and blue with tragedy or sadness (Peretti, 1974). In an article on the emotional content of pictures Pettersson (1984) echoed these results stating that persons in western cultures tend to link red and yellow with warm, active, exciting and happy events, and green and blue with cool, passive, peaceful, and controlled events. Bloomer (1976) also lists some commonly held meanings of colors: red-strong, yellow-cheerful, green-growth, blue-calm, violet-mysticism. Other studies have shown similar results (Murry & Deabler, 1957; Schaie, 1961; Wexner, 1954; Wright & Rainwater, 1962).

In a study of children, 12 to 16 years of age, Beck (1960) found that certain colors are associated with stimulus words more frequently than expected on the basis of chance. A similar study by Lawler and Lawler (1965) of nursery-school children indicated that associations exist between color and mood at a young age. Half of the children were told a short, happy story, and the remaining half were told a short, sad story. Afterward they were asked to color a drawing of a girl's dress with either a brown or yellow crayon. The specific color was not stated in the study. Those who were told the happy story colored the dress yellow more frequently as compared to those who were told the sad story. The latter group tended to color the dress brown. In a replication of this inquiry, using 307 Japanese boys and girls aged five to six, results showed that the children matched brown with sadness and yellow with happiness (Yoshikawa, Yagashita & Matsuda, 1970). The specific colors of crayons used in the two experiments were not described; however, it should be noted that yellow and brown are the same (or only slightly different) in hue. Brown is a low value of yellow. Therefore, the value and/or saturation of the colors would have had a major influence on the results.

Some associative meanings ascribed to colors vary, depending on individual and cultural differences. In a study of 23 cultures, Adams and Osgood (1973) used semantic differential scales to measure evaluation, potency, and activity. Results on the evaluation scale supported the general preference for cool colors (blue and green) as compared with warm colors (red and yellow) and agree with previous findings by Adams and Osgood (1973) that red is a potent color while gray and black have low potency. Although there were marked differences for some cultures, the findings generally coincide with previous research reporting that red and black are active colors.

In summary, colors do have some apparent common meanings that are probably learned, not inborn. However, the studies on color associations like those on color preferences are difficult to compare because of the varied methodological techniques employed and the lack of specific color designation. The colors used are frequently reported only by the hue, ignoring the attributes of value or saturation. Konker (1985) stated that meanings of the colors we see are social and cultural in nature. Wexner (1954) suggested that cultural, biological, and learning factors may influence color meanings and mood associations. Additional research is needed in this area.

Color Harmony

How well colors go together is dependent on the specific colors, the size and shape of the colored areas, and the overall context. It also depends on personal likes and dislikes which vary from person to person and with the same person from time to time (Burnham, et al., 1963). Evans (1940) lists the chief color, the range of colors, and the relative areas of colors in a scheme as key factors in determining color harmony. He also points out that any two colors may appear harmonious if there is enough difference in their relative areas. For example, two large adjacent areas of yellow and blue may not be rated as harmonious, but a small area of yellow on a background of blue may be rated as harmonious. Even though there are no absolute rules for color harmony, Burnham, et al. (1963) state that colors appear to be harmonious if the color combinations are familiar to the viewer and if they have similar attributes of hue, value, or saturation.

COLOR AND LEARNING

There is considerable evidence that the use of color in instructional materials does not necessarily result in increased learning, even when color was designed to be used as a cue (Bretz, 1970; Chute, 1979; Cox, 1976; Lamberski, 1975; Lumsdaine, 1963). This result has been shown in many studies over a long period of time using a variety of subjects and content areas.

In a color-effectiveness study conducted at Fort Monmouth, typical army training procedures were used with 11 different television lessons (Kanner & Rosenstein, 1960). No significant differences were found in learning between monochrome and colored versions. One quote from the study is particularly interesting:

> For example, in reading color coded resistors, monochrome television trainees would hear that the color red had a certain value but only see it as a shade of gray. It seems reasonable to assume that for this type of learning, hearing the name of a color and a particular value or function during training is adequate for later seeing this color and remembering its value or function. (p. 251)

They concluded that words can substitute for colors in the learning process and transfer can occur when color is used in the performance situation (Kanner & Rosenstein, 1960). It was pointed out in the discussion section of this study that there was little attempt by persons producing the television lessons to exploit the use of color in the color versions. It was used in the manner typically used in the Fort Monmouth instructional program.

Johnson and Roberson (1979) raised the question, by the late 1970s, of whether the prevalence of color television in American homes would result in a difference in learning from black-and-white versus color as compared with the studies conducted in the 1950s. Subjects were 318 persons in four groups: first grade, sixth grade, ninth/tenth grade, and adult. The materials used were colored and black-and-white versions of films whose content was in the cognitive domain. No significant differences were found in the scores of immediate or delayed tests.

In a study of color and learning conducted at Pennsylvania State University, 60 students in physical science classes were divided into two groups (Scarpino, 1971). The control group received and used black-and-white materials. The experimental group received and used colored materials. No differences in achievement or in the time needed to complete achievement tests were found. A questionnaire developed by the investigator did indicate that the group exposed to color strategies was in favor of color in textbooks, lab manuals, and overhead transparencies. Similar results favoring color were reported by other researchers when comparing the value of color and black and white (Casey, 1972; Dooley & Harkins, 1970; Frey, 1972; Katzman & Nyenhuis, 1972; Morgan, 1971; Napoli, 1982; Reich & Weisner, 1972; Vandermeer, 1954; Webster & Cox, 1974).

In reporting the results of a study comparing the effects on learning of black-and-white television versus colored television presentations, Link (1961) reported no significant differences. However, he did note that of the persons who saw black-and-white and color versions, more than 89 percent preferred color. In a paper analyzing the functions of color in instructional materials, Chute (1979) also indicated that learners prefer color versions even though they do not consistently learn better from them. In a comprehensive review of studies on color, Lamberski (1980) stated that there is conclusive evidence that colored materials are preferred by learners.

It was reported in a study of the teaching value of colored versus black-and-white transparencies that students expressed a preference for colored transparencies and those who viewed colored transparencies had a more positive attitude toward transparencies than did those who viewed black-and-white transparencies (Isaacs, Gillmore, & Pettit, 1972). Winn and Everett (1979) reported that color influences the affective meaning of some pictures and has greater impact with young learners.

Research findings indicate that random use of color generally is not of value in increasing learning, but is preferred and does add interest. Purchasers of instructional materials buy colored materials even when black-and-white materials are more economical. Therefore, it is important for media designers to use color in as effective a manner as possible. Dwyer (1971a) pointed out that color will not automatically make an illustration more effective, and that the use of color may have to be justified in terms of contributions to specific kinds of learning. These areas would include attention, search tasks, retention, and other measures.

Attention

Color seems to have some effect on attention, however, there is not a lot of evidence to support this assumption. In a study of color as an attentional cue in discrimination learning, Allington (1976) found that color can serve to focus attention on relevant cues. Thurmon (1974) found in a study of the attention value of black-and-white versus color television that university students attended significantly longer to colored versions. It is interesting to note that Nathanson (1977) found the reverse effect for a group of retarded adults. Eye movement recordings showed that black-and-white versions of cartoon, live action, and pixillation films had greater attention value than colored versions. In a research study on color coding, Lamberski and Dwyer (1983) concluded that color is an attention-getting device that can provide measurable effects on learning that cannot be accounted for by words and labels. One of the conclusions supported in a study by Wu and Dwyer (1986) was that color used in print examples will aid a student to focus on central information and reduce information processing time when used to complement externally paced oral instruction. Levie (1973) pointed out that color can facilitate learning when it focuses attention on cues that might otherwise not be noticed.

Search Tasks

Color is useful for search tasks. Christ (1975) reviewed 42 studies conducted between 1952 and 1973 and concerned with search tasks. He concluded that the evidence shows that color is more effective than black-and-white. Also, color identification is more accurate than size, shape, or brightness. Cahill and Carter (1976) reported a gain in efficiency, indicated by decreased search time, with codes of up to five colors.

In a study of the effectiveness of color coding for information location on maps, subjects using maps on which checkpoints had been color-coded were able to locate these points in significantly less time than subjects using maps that were not coded in color. The conclusion of the study was that color is an effective cue for information location (Shontz, Trumm, & Williams, 1971). Wedell and Alden (1973) hypothesized that color would enable air traffic controllers to rapidly code and update information. Color was not found to be better than numeric coding for identification or for determining position of items in a matrix. Color was found to be useful in grouping information. This attribute would be useful in determining quickly which planes were at the same altitude. The authors suggested that color should not be used as a primary information source, but should be used as an alerting function, as an aid to searching, and as a means of stratifying a display.

Retention and Other Objective Measures

One theoretical basis for expecting that color can improve student achievement is based on realism theories such as those of Carpenter (1953), Dale (1946), Gibson (1954), and Morris (1946). The basic assumption is that learning will be more complete as the number of cues increases (Dwyer, 1971b). There is some evidence that color has a positive influence on retention. Using adult subjects, Zimmerman (1976) compared black-and-white and colored slides of pictures from magazines. He found that recognition memory for colored versions was superior to that for black-and-white versions and concluded that color should be considered if the learning task is recognition and if the visual materials are highly realistic.

Using colored and uncolored versions of both negative and positive slides of line drawings of familiar objects, Marcyes (1981) found that with an adult audience the colored versions resulted in significantly higher recognition scores. This result was particularly true for slides that were in a negative format (i.e., clear or colored lines on a black background).

Using color, nonrealistic color, and black-and-white slides with college students, Berry (1977) found that both color versions were superior to black-and-white for an immediate recognition memory test. Only the nonrealistic color was superior for delayed tests (Berry, 1977). This may have been due to the effect of novelty. In 1984, Berry compared field-dependent students with field-independent students for recognition memory of black-and-white, colored, and nonrealistic colored slides. Field-independent persons were generally superior in recognition memory. For the total group, color versions resulted in higher recognition-memory scores.

In a later study, Berry (1991b) used pictures of common household items in four visual formats that differed in complexity. The four formats, from simple to complex were: (a) black and white line drawings; (b) black-and-white photographs; (c) non-realistic color photographs; and (d) realistic color photographs. Subjects were 40 volunteers from a graduate education program who were randomly assigned to four treatment groups. Berry found that as the variable of visual complexity increases, so does the degree of recall. On the basis of his ongoing research on visual complexity and pictorial memory, Berry (1991a) concluded that in recall tasks, realistic color was most effective, followed by black-and-white, and then line drawings. He further suggested that nonrealistic color was the least effective for recall and may inhibit encoding of information.

Jesky and Berry (1991) studied the effects of pictorial complexity and cognitive style on recall. The 86 undergraduate subjects were administered the Group Embedded Figures Test (GEFT). Subjects were divided into three groups by score: field-dependent, indeterminate, and field-independent. Three different collections (32 per set) of visuals depicting common household items were used. Each set was photographed in color, in black-and-white, and converted to line drawings to create slides. Results indicated that the cognitive style factor of field dependence was not significantly related to recall. Realistic cues (e.g., photographs), however, were more effective coding devices than were less realistic cues (e.g., line drawings). Dwyer and Moore (1992) found color coding to be an effective instructional variable for maximizing information processing for field-dependent learners on the criterion measures employing visually oriented tests. On verbally oriented tests, color coding was not found to be effective. They suggest that color coding helped provide learning structure which allowed field-dependent learners to reach a level similar to that of field-independent learners.

The most exhaustive research in the area of color coding has been conducted by Dwyer, Lamberski, and their associates. Printed instructional materials on the human heart were developed in which color coding was carefully integrated for words and pictures in both learning materials and tests. Color versions of the learning materials resulted in higher scores on terminology, comprehension, identification, and drawing tests. Using color in the test items had no effect. Lamberski and Myers (1980) concluded that an integrated color code provides the greatest potential for retention during the learning process. Berry and Dwyer (1982) reported similar results for immediate tests, but noted that this effect was lost on delayed tests. The superiority of color was believed to be enhanced by the self-pacing which allowed learners to use more of the information presented, including color. For a more complete review of this research see Lamberski (1980), and Dwyer and Lamberski (1982–83).

The key factor relating to color and cognitive learning seems to be that it is of value when it emphasizes relevant cues, is used as a coding device, or when it is a part of the content to be learned (Dwyer & Lamberski, 1982–83; Levie, 1973; Pruisner, 1993; Wedell & Alden, 1973).

Non-objective Measures

Some research studies using measures such as verbal or written responses indicate that colored versions of materials do have some influence that is not present to the same degree in black-and-white versions (Webster & Cox, 1974). Stone (1983) reported that in a study using Liberian schoolboys as subjects, color presentations elicited more responses than black-and-white presentations. Vollan (1972) conducted a study comparing responses to black-and-white, realistic color, and contrived color pictures. Ninety sixth-grade students were shown pictures for one-half second and asked to describe in writing what they saw. Those who saw realistic color pictures reported dynamic content more frequently than those who saw black-and-white versions. Those seeing black-and-white pictures reported dynamic content more frequently than those viewing contrived color. The latter finding was attributed to the effect of the realism of the black-and-white versions.

Scanlon (1967) conducted a study using two random groups of journalism students who watched the funeral of the governor general of Canada in either black-and-white or color. Those who watched the color versions reported more emotional content, while those viewing the black-and-white versions made more detailed reports and made more remarks about the commentators. The next year a similar study was conducted using black-and-white and color versions of the Grey Cup football game. Again there was more emotional content in the reports of those who watched the color version and more detailed reports by those who saw the black-and-white version (Scanlon, 1970). Scanlon suggests that the color versions create emotional effects that detract from attention to details.

Color and the CRT

In recent years several researchers have conducted studies specifically related to the use of color on cathode ray tubes. Several pertinent examples of this research follow.

Pastoor (1990) describes two experiments. The first examined legibility and preference for computer screen displays of light-on-dark and dark-on-light text material on colored backgrounds. The results were congruent with Gustin's (1990) and Cuttill's (1991) preference results in which subjects preferred blue and cyan backgrounds for white lettering when displayed as projected slides or on a CRT. For dark text on light-background screen displays the acromatic (white) and low-saturated backgrounds were preferred.

The second experiment investigated the replicability of the results of the first study by allowing subjects to examine more thoroughly a reduced sample of the color combinations (Pastoor, 1990). The ratings in the two experiments were highly correlated. This suggests that spontaneous ratings of display colors are not strongly influenced by examination time.

The Pastoor (1990) article treats all aspects of the two experiments in detail that cannot be covered in this paper. There are, however, several conclusions that are particularly relevant:

- There is no evidence to suggest that there is a differential effect of hue on legibility or preference. The only exception is that blue or cyan backgrounds may be favorable for displays with light text on dark backgrounds.
- The most important influence on preference ratings is saturation. Low-saturated color combinations yielded the most preferred results.
- There was no influence of polarity on subjects' performance ratings.
- There was no differential effect of color on performance when character size and contrast were set for adequate legibility.

In a series of three studies conducted by Anglin and Towers (1993), subjects viewed, on a computer screen, 45 matrices of letters or words on a variety of background colors. In the first study, subjects scanned matrices of letters counting the number of times a target letter appeared in each matrix and entering it on the computer. Error rates and the time spent scanning each matrix were recorded on the computer. In the second study, subjects were instructed to scan matrices of words as quickly and accurately as possible while counting the number of words and recording them on the computer. In the third study, subjects viewed each of the matrices of words and rated them on a scale of 1–10 in terms of the ease of reading the words on a screen.

In the discussion of their results, Anglin and Towers (1993) pointed out that color combinations of green on magenta, magenta on red, red on magenta, blue on red, and blue on black produced relatively high scanning times for the letter and for the word matrices. These same colors were also rated difficult to read. They noted that many color combinations that yield short scanning times have a high contrast ratio, although contrast ratios were not measured. It is assumed that they referred to contrast of value (lightness or darkness) and not of hue. Such results would be consistent with research using slides or print which indicate that value contrast is a key factor in legibility.

Color combinations with low error rates and high preference ratings by viewers included white on red, yellow on cyan, white on blue, yellow on green, white on magenta, yellow on black, and white on cyan (Anglin & Towers, 1993). It is interesting to note that no combination of colors produced low mean scanning times, low error rates, and also high viewer preference.

Hoadley and Jenkins (1987) conducted two studies relating to the use of color on line graphs, pie charts, and bar graphs presented on a CRT. Monocolor as well as solid and patterned multi-color stimulus materials were used. Several conclusions were reported:

- The use of solid multi-colored presentations resulted in improved performance as compared to monocolored presentations.
- Solid colors without any patterning were the most effective way to utilize color in multi-color information presentations.
- The supplanting effect of color was evident. As an example, color was useful in judging size differences without looking at the scales on the axes of the graphs.

In a report of studies carried out in Sweden, Pettersson (1991) listed several pertinent recommendations for using color for presenting text on CRTs:

- The best text color is black which provides good contrast with most background colors.
- The best combination is black on a white or yellow background.
- Text can be easy to read in any color provided the background is carefully selected.
- The best background color for colored text is black which provides good contrast with most text colors.
- Optimum brightness contrast between text and background is about 8:1 or 10:1 (i.e., the text is 8 to 10 times as bright as the background).
- Colors such as blue, green, and red are liked very much, but they do not improve the accuracy of reading messages.

In a paper on making computer displays legible, Shurtleff (1980) reinforces findings of other researchers. He points out that white and colored symbols near the middle of the spectrum (e.g., yellow and green) provide better performance for the accuracy and rate of symbol identification than colors near the ends of the spectrum (e.g., blue and red). This effect is related to the difference in the way colors focus in the eye. Shurtleff also emphasizes the problem of the confounding effect of brightness and contrast when determining the effects of color on accuracy and speed of symbol recognition.

Several authors including Faiola (1990), Faiola and DeBloois (1988), Hoekema (1983), Rambally and Rambally (1987), Strickland and Poe (1989), (all cited in Milheim & Lavix, 1992), list several specific guidelines for using color for CRT presented materials:

- Use a maximum of four to six colors per screen.
- Be consistent in general color choices throughout a program or program section. Be especially careful to be consistent in color coding.
- Use color to link logically related information.
- Avoid combinations of complementary colors that are the same value, such as blue/orange, red/green, and violet/yellow unless used with extreme discretion.
- Use brighter colors for the most important information.
- Use color to highlight errors.
- Use a range of grays to provide a neutral background for two or three other colors.
- Use commonplace color coding, such as red for stop, green for go, and so forth, but research cultural characteristics for color use if designing for cultures other than one's own.
- Use significant brightness contrast between text color and background color to increase readability.

SUMMARY

Color can be looked at in many ways. Three of these are:

- Color as Seen—Physiological: adaptation, arousal effects, and acuity.
- Color as Seen—Psychological: color preferences, the meanings of color, and color harmony.
- Color and Learning: attention, search tasks, retention, and non-objective measures.

Color as Seen—Physiological

The appearance of any color depends to a considerable extent on the color or colors seen simultaneously or sequentially. Colors will look lighter against a dark background and darker against a light background. Similarly, a color will appear to be of higher saturation when seen against a background of its complementary hue (e.g., yellow on blue) than when seen against a background of a similar hue (e.g. yellow on red). Reds and oranges seem to advance and blues and greens seem to recede. Colors at the ends of the spectrum, red and violet, seem to result in greater arousal, and colors in the middle of the spectrum, yellow, green, cyan, seem to be best for discriminating detail.

Designers of instructional materials can use these effects to enhance the effects of color in instructional materials. Objects can be made to stand out or to blend with the background by careful choice of color based on what is known about adaptations. For example, a designer might use a blue background to emphasize a yellow or brown object.

Since red has an arousal effect, it would seem that the use of red would be more effective than a color from the middle of the spectrum to attract and hold attention. This needs to be tested because it cannot be assumed that the result of viewing a slide or a film is the same as the result of being exposed to colored swatches of paper. Acuity seems to be best when colors in the middle of the spectrum are used. However, there is little definitive research indicating specific colors that should be used for instructional materials when legibility is critical. For lettering, size is a more important factor than color. Whenever distinctions between elements must be made, it is necessary to consider the fact that many persons are color deficient to some extent. For such persons increasing hue contrast is helpful, but the most important factor is maintaining high contrast of values. High value contrast is also important when producing film, video, or computer programs in color that may be viewed in black-and-white. A red and green of the same value could look nearly identical if transferred to black-and-white.

Color as Seen—Psychological

It has been shown in many studies over a long period of time that color preferences are similar regardless of age or cultural differences. Cool colors are generally preferred and the preference for high chroma colors decreases from grade 4 to 12.

Although there are some cultural differences, colors are often associated with meanings that are common to most people. The most widely held meanings relate to a scale ranging from calm to exciting. Blue and green tend to be related to calm while red and orange tend to be related to exciting. Also, with the exception of small children, most persons associate the blue end of the spectrum with cool and the red end of the spectrum with warm. Value or brightness seems to affect the mood attributed to colors more than hue. Colors of high value are seen as light and airy while dark colors are seen as heavy and somber.

Color harmony is dependent on many factors. Three of the most important factors relate to the organization, familiarity, and similarity of attributes of the colors used. Harmony is also related to personal likes and dislikes which vary greatly between persons and with the same person at different times.

It is important to consider the psychological aspects of color when designing instructional materials. Colors should be chosen that are consistent with the message that is being communicated and that are appropriate for the intended audience. For example, use preferred colors, blue and cyan, for background colors and bright warm colors, red and yellow, to highlight important information. Use bright warm colors for material intended for young children.

Color and Learning

Random use of color is not generally associated with increased learning even when color would seem to be a factor, however, color has some positive effects on attention and is useful in search tasks, especially when other cues are not distinctive. There is some evidence that color can increase retention. This is especially true when color of words and pictures is carefully integrated and used during the learning stage. Color also affects the emotional

Table 1 ☐ Suggested Uses of Color

General	Use color to add reality.
	Use color to discriminate between elements of a visual.
	Use color to focus attention on relevant cues.
	Use colors to code and link logically related elements.
	Be consistent in general color choices throughout materials.
	Use colors such as highly saturated red and violet to attract attention and to create an emotional response.
	Use highly saturated colors for materials intended for young children.
	Consider commonly accepted color meanings such as red and yellow are warm, green and blue are cool, red means stop, green means go, etc.
	When producing materials for persons from varied cultures consider the meanings they attribute to colors.
Symbols	On black backgrounds use a moderately high brightness color for symbols.
	On white backgrounds use a low brightness color for symbols.
	When using white symbols on colored backgrounds use backgrounds of low to medium brightness such as medium brown, green, cyan, or blue to optimize legibility and viewer preferences.
	When using black symbols on colored backgrounds use backgrounds of medium to high brightness such as light yellow, green, cyan, or blue to optimize legibility and viewer preference.
	Use moderate to high brightness contrast between symbols and background. Avoid very low brightness contrast. Avoid very high brightness contrast, such as black and white or black and light yellow, unless viewing will be under high ambient light conditions.

responses that viewers make to films, videotapes, and other media. Based on the studies reviewed, suggested uses of color in instructional materials are listed in Table 1.

Further Research

From the point of view of designers of such instructional materials as slides, overhead transparencies, and CRT displays, there is need for further research in terms of legibility and preferences of viewers. Anglin and Towers (1993) suggest replication of their study with significantly more subjects to further test scanning times, viewer preferences, and their relationships. The studies by Gustin (1990) and Cuttill (1991), are limited in their application because they only used white lettering on colored backgrounds. Conducting similar studies, examining legibility and preference, and using colored lettering on colored backgrounds would provide useful information for designers because such combinations are commonly used on instructional materials and on video titles and video bulletin boards.

Many instructional materials are being produced for international markets. It would be important and interesting to conduct additional research that included the element of culture. In a study of Jordanian and American cultures, Abu-Jaber (1988) found that there were cultural differences in response to colors. He further concluded that color in instructional materials could be more effective if added attention was given to the selection and use of color. Past research on color preferences of persons from varied cultures has generally used color swatches, not realistic instructional samples. Similarly, studies using subjects with learning disabilities might be useful in providing guidelines for improving design of materials for those audiences.

Most studies of color images displayed on a CRT have been done with low-resolution monitors. Replicating previous studies with a high resolution monitor and/or comparing the results of studies done using various settings on multi-scan monitors could provide additional useful data. In any further research on color as it relates to learning, it is critical to specify the colors used as accurately as possible to assist in interpreting the research and to provide useful guidelines for designers.

Although the measurable effects of color on learning may be slight, colored materials are preferred and they are used almost universally. To increase the impact of their products, designers of instructional materials need to use color wisely by paying attention to the physiological and psychological effects of color and the effect of color on learning. □

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