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ABSTRACT

For 15 years an ongoing research project at the University of Pittsburgh has focused on the effects of variations in visual complexity and color on the storage and retrieval of visual information by learners. Research has shown that visual materials facilitate instruction, but has not fully delineated the interactions of visual complexity and color with cognitive processes. These studies used various combinations of slides in realistic color, black and white, line drawings, and nonrealistic color to test research hypotheses about visual complexity, color, cognitive styles, and cerebral asymmetry, as well as certain design factors and retention under either pictorial recognition or free recall situations. Groups of studies addressed the role of color realism as it relates to: (1) a pictorial recognition task; (2) the cognitive style factors of field dependence, impulsivity/reflectivity, and leveling sharpening; (3) hemispheric laterality; and (4) a visual recall task. Four general conclusions can be drawn from the findings of these studies: (1) all forms of color facilitate the recognition of visual material equally well, and are superior to monochrome materials as cueing devices; (2) in recall memory tasks, realistic color cueing is the most effective, followed by black and white and line drawing formats, with nonrealistic color cueing the least effective; (3) the processing of nonrealistic color information is lateralized to the right hemisphere while color and back and white processing are left hemisphere oriented; and (4) some evidence exists to suggest that field dependence may play a role in color information processing. (30 references) (BBM)

Title:

Visual Complexity and Pictorial Memory: A Fifteen Year Research Perspective

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VISUAL COMPLEXITY AND PICTORIAL MEMORY: A FIFTEEN YEAR RESEARCH PERSPECTIVE

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During the past fifteen years, an ongoing research project at the University of Pittsburgh has focused on the effects of variations in visual complexity and color on the storage and retrieval of visual information by learners. The purpose of this paper is to describe and summarize this group of studies and to draw conclusions from the research which may more clearly define the role of color and its application to the design of visual instructional materials.

Research has clearly indicated that visual materials facilitate instruction, but research has not fully delineated how the design factors of visual complexity, and color, specifically, interact with cognitive processes to produce this advantage. Over the years, a number of theoretic positions have addressed the question of visual complexity and realism from somewhat conflicting directions.

One position, termed "realism theories" by Dwyer, (1967) suggests that instructional materials become more effective as the degree of realism or the overall number of visual and contextual cues is increased. This hypothesis, often referred to as cue summation theory (Severin, 1967), was a popular component of many theories put forth during the 1940's and 1950's, (Dale, 1946; Morris,1946; Carpenter,1953; Gibson, 1954). A closer evaluation of these conceptualizations, however indicates two distinct interpretations. Initially, cue summation theory describes learning being enhanced as the total number of visual cues increases. No distinction is made between those which contribute to a more realistic portrayal of the information and those cues which are simply added to the display for enhancement purposes, such as color codes or stylized color for aesthetic appeal. In the case of color as a realistic descriptor, the cues contribute additional elaborative or meaningful information which may or may not be useful in encoding the visual information in memory. The simple addition of irrelevant visual information does not necessarily insure that the cues will be used by the viewer for memory storage unless a complex coding scheme is previously constructed. In either case, the method whereby the cue information is used in memory storage is still unclear. A conflicting set of theoretic orientations (Broadbent, 1958, 1965; Travers, 1964) suggested that the human information processing system is of limited capacity, and in times of high information processing, irrelevant cues may effectively block the processing of other, relevant information. These "filter" or information overload theories have been modified through research over the past years; however they remain highly credible descriptors of the processing system because they are supported by the large base of research relative to the limited nature of human information processing. Both of these theoretical positions received substantial research attention and became the focus of a large number of, albeit conflicting, research investigations. Studies conducted by Dwyer and others (1967, 1972, 1978, 1987) addressed the specific factors of complexity and color in visualized learning in a comprehensive and systematic manner The findings suggested that the complexity/color question is strongly dependent upon the specific instructional objective and learning task. Other research reported by Dwyer (1987) addressed additional factors among which were cognitive style, retention, visual realism and learner aptitudes. Additional research conducted over a period of many years has addressed the issue of the relative effectiveness of color in instructional materials. Studies, (Vandermeer, 1952; Kanner, 1968; Katzman & Nyenhuis,1972; Winn, 1976; Chute, 1979; Lamberski, 1980), have investigated this controversial topic with conflicting results.

The inclusion or absence of color information can be regarded as one dimension of visual complexity. Color can function in a dual role when used in visual displays. First it can serve primarily a coding function, providing additional information, but not providing any realistic description of the elements of the display. In this case, the effectiveness of color can be predicted by cue summation theory, but not by the realism hypothesis. Second, color can be used to present a more realistic version of the visual display. In this instance, in addition to providing a greater number of overall cues, it provides the viewer with more re. listic attributes or "handles" with which to store and consequently retrieve information. When color is used in this cueing role, its value could be predicted by the realism theories as well as by cue summation theory.

Based upon this vast accumulation of frequently inconsistent research data, a project was undertaken at the University of Pittsburgh to systematically investigate the relative effectiveness of the specific visual design factors of complexity and color realism, as they relate to certain pictorial memory tasks such as recognition, recall, and spatial analysis/synthesis. This paper is a summary of the findings and conclusions of those studies up until the present time.

RESEARCH MATERIALS

Much past research investigating the differences between color and monochrome visuals failed to take into account the fact that realistic color visuals contain intrinsically more information and consequently require more time for processing. In an attempt to resolve this methodological inconsistency as well as to more accurately assess the role of color in human information processing, Berry (1977) developed a set of stimulus materials for use in recognition studies. These consisted of 180 geographic scenery slides (120 stimulus slides and 60 distractor slides). The entire collection of materials was randomly divided into thirds. One third was retained as a realistic color group, a second third was recopied onto black and white slides and the remaining third was altered by photographic reversal to produce a non-realistic color group. By means of the photographic reversal process, the overall number of color cues could be held constant, while the degree of color realism could be manipulated.

A second set of materials was developed by Jesky (1984) for the purpose of testing hypotheses regarding recall memory. These materials were later modified by Berry (1990) to further test the realism hypotheses.The stimulus materials developed by Jesky were three sets of visuals, each produced in three visual formats; line drawing, black & white and color. Each set of visuals contained a different collection of common household items (32 per set) in a random arrangement. A nonrealistic version of these slides was produced by photographically reversing the color (realistic) slides of each set so that each color was systematically reversed to it's complementary value.

Additional modifications have been made to these materials over the course of this plan of research to accommodate or test specific, theoretical or related variables. These include digitized color reproductions, paired stimulus items and separation into specific object images.

The studies summarized in this paper used the research materials described above to test a variety of research hypotheses regarding visual complexity, color, cognitive styles and cerebral asymmetry as well as certain design factors and retention under either pictorial recognition or free recall situations. In the case of recognition memory experiments, the list learning procedure was employed, in which all subjects were first shown the set of 120 stimulus slides, individually for 500 msec. each. On a random basis, subjects were instructed to perform the masking task while viewing either the first 60 slides or the second 60 slides. The remaining, alternate 60 slides were viewed without performing the masking task. Subjects were subsequently presented a random distribution of all slides (stimulus and distractor) for 5 sec. each. During that time, subjects responded on a checklist either "old" (stimulus slide - seen before) or "new" (distractor slide - never seen). In those studies where pictorial recall memory was the task of interest, a free recall paradigm was employed. Subjects were presented with the stimulus materials for a brief study time (20 seconds) after which they were asked to recall as many items as they could from the stimulus images. The limited capacity of short term memory and rehearsal difficulty predicts that within a brief period of time (approximately four minutes), all items available in memory will have been recalled. Again, slight modifications were made in the methodology in some studies where variables of interest required specific presentation methods. In all studies, extreme care was exercised to maintain rigorous standardization of both materials and experimental procedures to ensure the generalizability of findings.

Over the time period of 1975 - 1990, a series of studies employed the materials and methods described to assess the effects of color and visual complexity. In all, fourteen studies have been completed or are nearing completion. A summary of the various studies conducted in this research program is presented in Table 1.

Insert Table 1 about here

SUMMARY of FINDINGS

This research project produced a number of significant findings and often confirmed the data of other studies. The results of each of these studies or groups of studies will be reviewed and summarized relative to the research variables of interest and the cognitive task under study.

By far, the largest group of studies addressed the role of color and specifically color realism as it related to a pictorial recognition task. These studies (Berry, 1977, 1982, 1983, 1984, 1990; Lertchalolarn, 1981; El Gazzar, 1984; Gobriyal, 1984; Waltz, 1990) utilized the recognition stimulus materials described above and focused on the comparative effects of different color presentation formats as one of their primary research questions. Each study compared three color modes, realistic color, nonrealistic color and monochrome (black & white) in the recognition task described. Other variables included in some of these studies are discussed elsewhere in this document. Early studies employed a simple analysis of correct recognition scores, however in most of these studies, analysis of the data was conducted via the method of Signal Detection Analysis. Signal Detection Theory (Swets, 1964) has been accepted as a reliable technique for assessing a subject's ability to describe the occurrence of discrete binary events and has been advocated as a means of reliably studying pictorial recognition memory (Snodgrass, Volvovitz, & Walfish, 1972; Loftus & Kallman, 1979; Loftus, Greene, & Smith, 1980; Berry, 1982).

The data obtained in this group of studies collectively indicated that significant differences generally exist between both realistic and nonrealistic color and black & white formats in favor of the color versions. This finding has consistently appeared with only two partial exceptions. The first is related to digitized pseudocolor, a variation of the nonrealistic color format that reduces the amount of color information systematically via a digitizing equation. In this case (ElGazzar, 1984, the realistic materials were superior to black & white, but the digitized images were inferior to the monochrome format. The second case (Berry, 1990; Waltz, 1990) incorporates the concept of cerebral laterality and suggests that nonrealistic color is superior to realistic color in right hemisphere processing only.

The generalized finding in these studies, however, lends strong support to the cue summation orientation, but does not necessarily support the notion that more realistic materials are intrinsically more effective in facilitating recognition.

The second largest group of studies focused on various cognitive style factors, specifically; field dependence, impulsivity/reflectivity and leveling sharpening. Generally, cognitive styles refer to "consistent modes of processing information" (Messick,1976), which are stable over time. Additionally, cognitive styles tend to incorporate a strong visual/perceptual component and have been significantly related to learning.

The most thoroughly researcher cognitive style is field dependence which was identified by Witkin, Oltman, Raskin & Karp (1971). This factor is functionally defined as the differential ability of individuals to separate figure from ground or to overcome "figural embeddedness". This ability of figural disembedding is generally considered to be representative of the more global ability to impose structure upon perceived information. Skill in this area has significant implications for the design of instructional materials.

The second cognitive style, impulsivity/reflectivity (Kagan, Rosman, Day, Albert & Phillips, 1964; Kagan, 1969), refers to the differential characteristic of some individuals to respond quickly yet inaccurately in a response situation (impulsives), while others respond more slowly but with more accuracy (reflectives). Research has indicated that this style has important consequences for instruction as well as the development of visual instructional materials because it also impacts upon an individual's ability to "read" a visual display.

The third cognitive style is leveling/sharpening which was identified by Holzman & Gardner (1960). Gardner & Long (1960) defined leveling/sharpening as "individual consistencies in memory organization as a function of assimilation between new stimuli and memories of stimuli experienced previously". In current practice, this construct refers to the ability of some learners to skim over significant differences or differentiations in content (levelers) while others tend to make discriminations which are not really valid (sharpeners).

Research which explored color realism and complexity in relation to cognitive styles was conducted by Wieckowski, (1980) (field dependence, impulsivity/reflectivity); Lertchalolarn, (1981) (field dependence); Gobriyal, (1984) (leveling sharpening) and Berry, (1984) (field dependence) as well as visual recall research by Jesky, (1984) (field dependence). With regard to studies which investigated field dependence it was found that in some cases field independent subjects benefitted more from color materials. In one instance, field independent individuals scored significantly higher on visual tasks generally, although in most cases, no significant relationship was found between field dependence and the use of color in stimulus materials. Other research which investigated impulsivity/reflectivity and leveling/sharpening did not find significant interactions with the color variable.

A third area of theory which was explored relative to color realism was hemispheric laterality. Studies by Berry, (1990) and Waltz, (1990) focused on the effect of variations in color information processing in both hemispheres of the brain, using different perceptual testing methods. Research on lateral cognitive functions has suggested that the two hemispheres of the brain are partially specialized for particular skills, with the left hemisphere oriented toward language and analytical skills and the right associated with visuospatial processing (Hellige, 1980; Sperry,1984; Gordon, 1986). Similarly, researchers (Davidoff, 1976; Jorgenson, Davis, Opella & Angerstein, 1981) have found evidence to conclude that color processing may be a right hemisphere activity.

The research conducted in this series of studies used two methods of localizing cognitive activity to different sides of the brain. Berry, (1990) used a verbal masking task to inhibit left hemisphere processing, while Waltz, (1990) used a perceptual method; projecting different images to the right and left visual hemifields. Results of both studies were highly similar and suggest the same conclusion. Significant differences existed for the processing of color information in the right hemisphere. Nonrealistic color seems to be processed primarily in the right hemisphere while other color and monochrome information is processed much more in the left hemisphere. Conclusions suggest nonrealistic color information is less verbally related than realistic color information and is thereby processed in a different manner and location.

A third study, Alfahad (1990), investigated visual recall memory with results which implied that color processing is localized more strongly to the right hemisphere. Color realism was not explored however.

Three studies investigated color realism or complexity relative to a visual recall task (Jesky, 1984; Alfahad, 1990; Berry, 1991). Memory research indicates that while recognition memory data describe the contents of memory, recall data provides insight into the methods whereby information is encoded into memory (Anderson & Bower, 1972). Since color cueing information is assumed to be a significant contributor to memory storage, it would appear important to investigate the effect of the type of color cues on the encoding process via a recall task. Two of the studies investigated the variable of visual complexity using color (realistic), black & white , and line drawing illustrations. In both cases, color was found to be superior to black & white, which was, in turn, superior to line drawing formats. The third study addressed the extended question of color realism with the same results as the first two studies regarding realistic color, monochrome and line drawings. Nonrealistic color was found to be inferior to all of the other treatments. It can be concluded from these findings that realistic color is reasonably effective in facilitating the encoding process, while nonrealistic color does not seem to play a useful role. To the contrary, nonrealistic color may actually inhibit the encoding process.

CONCLUSIONS

Based upon these findings, four general conclusions can be drawn:

1. All forms of color facilitate the recognition of visual material equally well. Both realistic and nonrealistic color materials are superior to monochrome materials in terms of their utility as cueing devices.
2. In recall memory tasks, realistic color cueing is most effective, followed by black & white and line drawing formats. Nonrealistic color cueing is the least effective method, and may inhibit encoding.
3. The processing of nonrealistic color information is lateralized to the right hemisphere while color and black & white processing is left hemisphere oriented.
4. Some evidence exists to suggest that field dependence may play a role in color information processing.

With regard to recognition memory, conclusion one supports cue summation theory, but nor necessarily the realism hypothesis. This may be explained by considering the nature of the recognition process. Recognition is a test of the contents of memory, not the effectiveness of the encoding/retrieval processes which store and access that information. In a recognition experiment, the subject does not need to search for the information, but rather match it with information already made available by the experimenter. In this case, the additional cues provide a larger pool of information with which to make the match. The relevance or realism of the cues is of little consequence, only the number are significant.

In recall memory, two cognitive processes are functioning; memory search and recognition. The subject must first search through memory to locate an appropriate image, then a recognition test must be performed. The nature of the search process reveals how the visual cues function. Information which is encoded using realistic cues will be compared with a previously stored, generic schema of the image and a reasonably complete match is made. Upon retrieval, the image will be easy to retrieve because it fits a common schema with few variations. In the case of nonrealistic cues,however, there may be a substantial mismatch between the actual appearance of the image and the generic schema previously stored in memory. Encoding will be more difficult because the new image differs significantly from that incorporated in the schema. This conflict may actually inhibit encoding and consequently make retrieval more difficult.

The data related to cognitive lateral functioning and color realism seem fairly clear, but conclusions drawn from them may be tenuous. It is apparent that nonrealistic color is processed primarily in the right hemisphere, possibly because it functions in a symbolic or coding role. In this way it could be thought of as simple images rather than more complex schemata. Realistic color or even black & white images, which are "familiar" have more complex semantic networks which include information and associations among images, verbal symbols and propositions. In short, the type of information which research has identified as being processed primarily in the left hemisphere (Gordon, 1986). Following this line of reasoning, it is apparent that nonrealistic, unfamiliar or unconventional images would have limited utility in left hemisphere processing and consequently are processed in a different manner in the right hemisphere.

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Table 1
Summary of Visual Complexity/Color Realism Studies

	VISUAL VARIABLE	LEARNING TASK	OTHER VARIABLES
Berry, 1977	Color Realism	Recognition	Delayed Retention
Wieckowski, 1980	Visual Complexity	Recognition	Field Dependence & Impulsivity/reflectivity
Lertchalolarn, 1981	Color Realism	Recognition	Field Dependence
Berry, 1982	Color Realism	Recognition	
Berry, 1983	Color Realism	Recognition	Multicultural
El Gazzar, 1984	Color Realism	Recognition	Digitized Pseudocolor
Berry, 1984	Color Realism	Recognition	Field Dependence
Jesky, 1984	Visual Complexity	Recall	Field Dependence
Gobriyal, 1984	Color Realism	Recognition	Leveling/Sharpening
Berry, 1990	Color Realism	Recognition	Cerebral Laterality
Alfahad, 1990	Visual Complexity	Recall	Cerebral Laterality
Waltz, 1990	Color Realism	Recognition	Cerebral Laterality
Berry, 1991	Color Realism	Recall	
Stanton, 1991	Color Realism	Recognition	Color Discrimination