The Mythology of Colour in Multimedia Screen Design: Art, Science, and Connoisseurship

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Abstract: The effective use of colour in designing computer screen displays is both an art and a science. The literature reflects this duality, bringing together advice based on experience, tradition, and opinion with that based on empirical research. As generalizations - whether based on empirical research or on practical experience - -are handed down from researcher or practitioner to novice, "truths" which may no longer be valid inadvertently get promulgated. Indeed, the literature appears to orbit a collection of common guidelines, a core of undefended advice based on little evidence. This article summarizes the results of an exhaustive search of the literature on the use of colour in screen design for instructional purposes. Critical analysis of the papers contributing to the knowledge base reveals that major problems exist with if, leaving precious little valid guidance to instructional designers, while appearing to offer a considerable amounf. Renewed research, and the development of a connoisseurial approach fo screen design which *values* the contributions of both research and aesthetic experience, are proffered as useful approaches.

Résumé: L'utilisation efficace de la couleur dans la conception de l'affichage sur écran d'ordinateur est à la fois *un arf* et *une* science. La documentation *écrite sur* le sujet réflète cette dualité en réunissant conseils et opinions basés respectivement sur l'expérience et *la* tradition, et sur la recherche empirique. Qu'elles soient basées sur l'expérience ou sur la recherche empirique, ce *sont des* <<généralisations= qui sont transmises *aux* néophytes par les chercheurs et les praticiens. Ces <<vérités>>, qui ne *sont* probablement plus valides, sont *perpétuées* comme par inadvertance. En effet, *la* documentation semble orbiter *autour d'un* ensemble de *lignes* directrices ou de *conseils non* défendus basés *sur des* évidences à peine prouvées. Cet article fait *le point sur les conclusions tirées d'une* recherche approfondie de la documentation écrite sur l'utilisation *de la couleur* dans la conception d'écrans *pour fin d'enseignement. Une* analyse critique des articles qui *constituent la base de la connaissance sur le sujet révèle que cell-ci* recèle de grands problemes. *En* effet, bien qu'il existe un grand *nombre de lignes directrices,* les concepteurs pédagogiques ne peuvent s'y rapporter *parce* qu'elles *sont peu* fiables. Une recherche *renouvelée et le développement d'une* approche *avertie, basées sur la contribution des chercheurs et sur l'expérience* esthétique, sont privilégiés *comme* approches *valides dans la conception de l'affichage sur écran d'ordinateur.*

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The effective use of colour in designing computer screen displays is both an art and a science. It is an art in two senses of the word: it is a "... system of rules or principles governing a particular human activity" (Hanks, 1986, p.83); and a collection of wisdom, based on experience, handed down from one practitioner to another. It is also an aesthetic undertaking, inasmuch as attractive screen displays are a goal. There is no shortage of advice and opinion on how colour should be used in screen design; a sizable literature exists which is composed largely or exclusively of experiential summaries.

There are also two kinds of science involved in designing colour screen displays: there exists a well-established knowledge base on the psychophysical aspects of colour, and there is also a considerable collection of empirical research on the use of colour on video display terminals (VDTs) and computer screens, and a number of summaries of this research. To avoid possible confusion between these two "branches" of science, we will refer to the latter as the "science" of using colour in designing screen displays.

This article looks at the "art"- some rules of thumb that advise on how to avoid the garish atrocities that are sometimes produced by neophytes, and the "science" — generalizations gleaned from empirical studies of screen design. To lay the groundwork for a closer look at the art and the science, we first undertake a quick review of the psychophysical factors, of which we have not done an extensive review as part of this article. Psychophysical processes relating to colour are well-understood, and the literature on them is well-developed, but relatively distinct from our purpose here.

PSYCHOPHYSICAL FACTORS

To briefly review some rather well-established concepts, there are four main characteristics of colour, each of which has importance in considering the use of colour in screen design: hue, brightness, saturation, and contrast (Adkins &Pease, 1991; Durrett & Trezona, 1982; England, 1984; Faiola, 1990; Faiola & DeBloois, 1988; Murch, 1988; Tufte, 1992). Hue is what we generally identify as colour, for example, red, blue, or mauve. Brightness (also known as luminance or value) is the intensity of light reaching the retina. A higher intensity is generally perceived as brighter, although individuals confronted with different colours at the same level of intensity will often perceive one as brighter than the other. Saturation (or chroma) is the interaction of hue and brightness, and is often referred to as the depth or richness of a colour. Saturation of a colour can be diminished by adding white; pastel colours are de-saturated. Finally, contrast is the relative perceived brightness of two colours on a display, and it is related to the notion of figure-ground in visuals. Contrasting colours are easy to separate visually. Another factor which can interact with the four characteristics mentioned above is the amount and quality of ambient light -the natural or artificial light in the setting.

Specialized cells in the retina of the eye called cones provide initial colour sensation through the stimulation of photopigments (light-sensitive chemicals). Most cones are concentrated in the centre of the retina, so that is the area of the eye most sensitive to colour, while little more than grays are perceived at the periphery of vision. Each cone contains one of three different types of photopigments, and each is sensitive to different wavelengths (hues) of light. Type 1 (blue photopigment) is insensitive to wavelengths longer than about 520 nm, so it responds exclusively to wavelengths in the blue to violet range. Type 2 (greenphotopigment) responds to everything, but is maximally sensitive to 535 nm. Type 3 (red photopigment) responds to everything, but is maximally sensitive to 575 nm. Colour is determined by an interaction among the three photopigments; the perceived colour is a mixture of the relative responses of the red, green, and blue photopigments, in much the same way as a television camera creates colour. Given a dramatic imbalance among the percentages of cells containing red (approximately 64%), green (approximately 32%), and blue (approximately 2%) photopigments, it is clear that the perception of colour is both highly specialized and physiologically biased (data from Murch, 1984).

CATEGORIES OF ARTICLES REVIEWED

There have been a number of recent major reviews of the literature pertaining to the use of colour that can likely be generalized to multimedia screen design. Some deal with colour more or less exclusively (e.g., Brockmann, 1991; Christ, 1975; Davidoff, 1987; Holcomb, 1991; Horton, 1991; Murch, 1987; Winn, 1991) while others deal with colour on screens in passing, as part of a review of a related topic (e.g., Gillingham, 1988; Hathaway, 1984; Isaacs, 1987; Mills & Weldon, 1987; Sawyer, 1985; Shaw, 1991; Tullis, 1983). In addition, there have been numerous reviews which are either mostly focused on topics other than the use of colour, or less comprehensive in nature (e.g., Chapman, 1993; Milheim & Lavix, 1992; van Nes, 1986). Finally, there are frequently brief reviews of related literature associated with empirical studies in related areas (e.g., Anglin & Towers, 1993; Baek & Layne, 1988; Baker, Belland, & Cambre, 1985, 1986; Bruce & Foster, 1982; Clausing & Schmitt, 1989, 1990; D'Angelo, 1991; Hativa & Teper, 1988; Kerr, 1987; Livingston, 1991; McDonald, Molander, & Noel, 1988; Ohlsson, Nilsson, & Ronnberg, 1981; Pace, 1984; Pastoor, 1990; Radl, 1980; Simmers, 1988; Tullis, 1981; Wright & Lickorish, 1988).

Table 1 classifies articles on the basis of whether they are primarily:

- summaries of empirical research (i.e., they do not include new empirical data);
- empirical studies (i.e., they do include new empirical data) that may include brief but not necessarily comprehensive reviews of related

literature; or

- non-empirical in nature (i.e., generalizations gleaned from experiential or theoretical propositions).

TABLE 1

Articles Dealing with Co/our Grouped According to Type of Information Included

Primary Article Type	Author(s)
Largely or Exclusively Summaries of Empirical Research	Brockmann, 1991 Chapman, 1993 Christ, 1975 Davidoff, 1987 Gillingham, 1988 Hathaway, 1984 Horton, 1991 Isaacs, 1987 Murch, 1987 Rice, 1991 Sawyer, 1985 Shaw, 1991 Tullis, 1983 Winn, 1991
Largely or Exclusively Empirical Research Studies	Anglin & Towers, 1993 Baek & Layne, 1988 Baker, Belland, & Cambre, 1985* Baker, Belland, & Cambre, 1986* Bruce & Foster, 1982 Clausing & Schmitt, 1989 Clausing & Schmitt, 1990 D'Angelo, 1991 Hativa & Teper, 1988 Holcomb, 1991 Kerr, 1987 Livingston, 1991 McDonald, Molander, & Noel, 1988 Ohlsson, Nilsson, & Ronnberg, 1981 Pace, 1984 Pastoor, 1990 Radl, 1980 Simmers, 1988 Tullis, 1981 Wright & Lickorish, 1988

TABLE 1 (continued)
Articles Dealing with Colour Grouped According to Type of Information Included

Primary Article Type	Author(s)
Largely or Exclusively Non-Empirical Summaries	Adkins & Pease, 1991
	Baecker & Buxton, 1987b
	Baker, 1983
	Brou, Sciascia, Linden, & Lettvin, 1986
	Collery, 1985
	Durrett & Trezona, 1982
	England, 1984
	Faiola, 1990
	Faiola & DeBloois, 1988
	Galitz, 1989
	Garner, 1991
	Heines, 1984
	Milheim & Lavix, 1992
	Murch, 1984
	Olson & Wilson, 1985
	Rambally & Rambally, 1987
	Reilly & Roach, 1986
	Shneiderman, 1992
	Steinberg, 199 1
	Thorell & Smith, 1990
	Tufte, 1990
	Tufte, 1992
	van Nes, 1986
	Waller, Lefrere, & Macdonald-Ross, 1982

*These two papers appear to report the results of the same study.

Instructional designers naturally turn to recent review articles in order to keep themselves abreast of the most current thinking on how to use technology most effectively. However, the advice they get there may not be the best possible. While we have no desire to impugn the scholarship of the authors of the articles mentioned above, or others, we wish to point out some major problems in most summaries of the literature dealing with aspects of multimedia, using the case of colour in screen design as a case in point. Through the normal practice of exemplary scholarship, myths and legends have crept into our knowledge base on screen design. Authors cite previous authors' works, but in their efforts to be comprehensive sometimes report outdated or only marginally related literature which then tends to become part of mainstream advice and generalization (much as a legend gets handed from one generation to the next). Thus a certain amount of current instructional design practice, as it is applied to screen design, may actually be based on myth. This phenomenon appears in both the "art" and the "science" literatures.

WHY COLOUR?

What does colour accomplish? Writers have attributed much to colour in instructional materials. Colour may promote deep processing of important information, aid in organizing lesson content, allow reasonable learner-control options, promote interaction between the learner and lesson content, and facilitate lesson navigation (Hannafin & Hooper, 1989). In some cases "color stirs the heart.. . and other vital organs" by influencing everything from blood pressure and endocrine functions to brain wave patterns and strength (Horton, 1991, p. 161).

In multimedia screen design, it has been claimed, colour can be used to link logically-related data; differentiate between required and optional data; highlight student errors; separate various screen areas such as prompts, commands, or input/output fields; emphasize key points; and communicate overall structure (Horton, 1991; Milheim & Lavix,1992; Rambally & Rambally, 1987; Strickland & Poe, 1989). While this list is not exhaustive, it illustrates the wide range of roles colour may play in instructional materials, and probably hints at the reason for so much confusion surrounding its use. The effective use of colour is tied intimately to the role it is intended to play in a particular instructional situation-it is difficult to talk about using colour out of the context it serves. What may be an effective use of colour for title screens may be wholly inappropriate in information screens, visual data bases, or testing contexts. For example, while claims are often made for the motivational value of colour in instructional materials, the findings on motivation are by themselves not strong enough arguments for using colour (Brockmann, 1991; Waller, Lefrere, & MacDonald-Ross, 1982).

THE ART

As well understood as the physiology of colour is, it provides little explanation for our opinions of colour and colour combinations. At the very least, opinions of colour are learned and highly associative. For example, as children we often had a "favorite colour" and we liked everything-clothes, toys, books- that matched our preference. Over time, we learned a variety of colour schemes, and in most cases our tastes became more refined. But even as adults, we are influenced by fashion, and may still associate our more sophisticated sense of colour with increasingly more sophisticated emotions, desires, or impressions. For example, even a cursory examination of changes in interior design from the 1950s to the present reveals a dramatic evolution of what were considered warm or even comfortable colour combinations. A lively debate still rages about the psychology of colour, and various claims are made for using colour in the environment to stimulate, calm, or enhance the performance of individuals.

There is a significant literature of opinion growing around screen design, and there is a large tradition drawn from earlier media which is being generalized, sometimes indiscriminately, to newer media. How does experiential information or advice have value? One often feels set adrift without guidance in the design of multimedia, and it is comforting to have guidelines — any guidelines — to justify decisions. A convergence of opinion is a good place to start when facts are scarce. At the same time, one must always be careful not to confuse a collective opinion with fact; such guidelines may in fact conspire to constrict creativity and promote the development of products which, over time, become hackneyed and trite. What makes us uneasy about depending primarily on experiential knowledge is that we often don't know how (or even by whom) certain generalizations were derived, what kinds of tasks they were derived from, and, particularly, when they were derived (as that often is related to the state of the art of display equipment). With these cautions in mind, this paper examines some advice available in non-empirical literature.

What advice is available about using colour in screen displays? There is considerable consensus on guidelines, although there are a few significant contradictions. One cannot easily judge from the material whether the consensus is based on independently derived judgements, or primarily on a shared and confined literature. Indeed, some of the more substantial guidelines emerge from the tradition of print (see, for example, Horton, 1991; Waller, Lefrere, & MacDonald-Ross, 1982).

We want to emphasize that the authority for the guidelines offered below is variable, and the comments offered after each set of principles are intended to summarize the main consensus of opinion rather than to endorse one explanation or approach. With these cautions in mind, guidelines and principles were extracted from the non-empirical literature and categorized. No attempt has been made to validate the guidelines; the purpose of the categorization is to locate points where opinions converge and diverge. Advice is broken into the categories of amount of colour, consistency, choice of colour, and coding and cueing with colour. Principles or guidelines within each category are listed along with sources of the advice. A HyperCard(TM) stack (Misanchuk & Schwier, 1995) which illustrates a number of these principles, and permits viewers to arrive at their own conclusions about various pieces of advice, is available from the authors. (Electronic mail requests are preferred, addressed to Earl.Misanchuk@USask.Ca)

Amount of Colour

- Use colour conservatively: limit the number and amount of colours used (Brockmann, 1991; Durrett & Trezona, 1992; Garner, 1991; Horton, 1991; Shneiderman, 1982).
- Limit the palette per screen to what the eye can actually keep track of at one glance (usually about six colours, depending on the complexity of the screen design). (Bailey & Milheim, 1991; Baker, 1983; Faiola, 1990; Faiola & DeBloois, 1988; Hoekema, 1983; Milheim & Lavix, 1992; van Nes, 1986).
- Design first for monochrome displays, and then add colour (Brockmann, 1991; Garner, 1991; Shneiderman, 1992).
- Long term users are capable of perceiving and responding to a broader range of colour and coding relationships, so the number of colours used can increase with experience (Faiola, 1990; Faiola & DeBloois, 1988).
- Use colours selectively to manipulate attention. Colour can be used to highlight text or graphics to make them conspicuous (Durrett & Trezona, 1992; Garner, 1991; van Nes, 1986).
- "Material presented in colour is generally processed faster than the same material presented in black-and-white." (Durrett & Trezona, 1992, p. 16).
- Use colour to help in formatting (Shneiderman, 1992).
- Use colour in graphic displays for greater information density (Shneiderman, 1992).
- Electronically generated colours take on different properties in relation to each other (England, 1984).
- Wavelength affects colour differentiation: luminance affects legibility (England, 1984; Murch, 1984).
- Changes in brightness seem to cause changes in hue for all colours except blue (470 nm), green (505 nm), and yellow (572 nm). These should be used where colour shifting due to luminance changes would be detrimental (Horton, 1991).
- As viewers age, higher levels of brightness are needed to distinguish colours.

As evidenced by the above principles, designers are less captivated by colour than one might anticipate. The most resonant advice among writers is to limit the amount of colour to what is useful or necessary, depending on the purpose of the product being developed. The notion of designing for monochrome first, and then adding colour, seems to offer a practical method of harnessing an indiscriminate use of colour. Another striking feature of the advice is the role played by luminance in the portrayal of colour. An instructional designer must consider more than hue when designing screens for legibility, contrast, and constancy.

Consistency

- Be consistent in colour choices (Brockmann, 1991; Faiola, 1990; Faiola & DeBloois, 1988; Milheim & Lavix, 1992).
- Carefully select colours for all visual devices such as touch screens, buttons, menus, and titles (Faiola, 1990; Faiola & DeBloois, 1988).
- If colour coding is used in an information system, it should be used consistently (van Nes, 1986).
- As with all uses of colour, consistency is crucial when using colour for coding information. (Durrett & Trezona, 1982; Shneiderman, 1992).

Using colour consistently may sound like obvious advice, but it is advice often ignored. Consistency is a hallmark of good instructional design; if items are consistent throughout instruction, then the learner can devote more energy to dealing with the content of a presentation than to learning (and re-learning) the conventions of the delivery system.

Choice of Colour

- In selecting colour combinations, make sure they are compatible (avoid saturated complementary colours such as blue/orange, red./green, violet/yellow) (Bailey & Milheim, 1991; Brockmann, 1991; Durrett & Trezona, 1982; Faiola, 1990; Faiola & DeBloois, 1988; Milheim & Lavix, 1992). Murch (1984) qualified this advice. He argued that opponent colours, especially desaturated colours, can go well together for simple colour displays.
- Gray is a versatile colour (Tufte, 1992). Use gray in inactive screen areas and backgrounds to enhance two or three other colours (Bailey & Milheim, 1991; Faiola, 1990; Faiola & DeBloois, 1988; Milheim & Lavix, 1992; Tufte, 1992).
- Avoid background colours too high in brightness and saturation (Bailey & Milheim, 1991; Faiola, 1990; Faiola & DeBloois, 1988; Horton, 1991; Milheim & Lavix, 1992).
- Against gray backgrounds use light, highly saturated borders for active windows. One suggestion is that yellow is the only colour satisfying this requirement (Tufte, 1992), while others argue that one should always use red, white, or yellow text on black (Durrett & Trezona, 1982). Regardless, attend more closely to brightness than hue for building contrast for legibility (Brockmann, 1991; Faiola, 1990; Faiola & DeBloois, 1988; Horton, 1991).
- Similarly, use high colour contrast for character/background pairs. Incorporate shape as well as colour when possible to make the system usable for those with colour-deficient vision (Bailey & Milheim, 1991; Garner, 1991; England, 1984; Milheim & Lavix, 1992; Tufte, 1992).
- Dark text on a bright background is more legible than the reverse (van Nes, 1986).

- Avoid using red and green at the edges of screens if you want people to notice those elements. People are less sensitive to red/green at the periphery of vision. If you must use them, make items blink before resorting to continuous display, to attract attention (Durrett & Trezona, 1982).
- Don't use blue for text — "limit blue to large nonfoveal areas" (Durrett & Trezona, 1982, p. 14), but use it as a background colour to enhance depth perception (Horton, 1991).
- Avoid using pure blue for text, thin lines, and small shapes. Individuals have difficulty focusing on blue (Horton, 1991; Murch, 1984).
- Strong colours should not be used over large adjacent areas. Use strong colours sparingly between dull background tones (Horton, 1991; Tufte, 1992).
- When a quick response is necessary, use colours with higher degrees of saturation (Faiola, 1990; Faiola & DeBloois, 1988).
- Use colours found in nature, particularly toward the lighter side: grays, blues, yellows. These colours are widely considered harmonious. (Tufte, 1992):
- For users with colour-deficient vision, use dramatic changes in colour to discriminate among elements by making changes in at least two of the three main colours. For example, displays in which only the red pigment is changed, while blue and green remain constant, will cause problems for these users (Murch, 1984).

The literature of advice on colour choice goes dramatically beyond issues of aesthetics. Many of the recommendations are based on the physiological response of the eye. For example, the advice on how to use blue is based largely on the inability of the eye to focus clearly on blue images. Thus, the general advice is to relegate blue to a supporting role in screen design. There are, however, aesthetic concerns that complement the physiological explanations. Many writers expressed displeasure with garish colour combinations, and one went so far as to call for the harmonious colours found in nature. Regardless of whether the justification is scientific or aesthetic, the general consensus of opinion is to avoid using highly saturated, bright colours for text, large areas, and backgrounds; or adjacent to other strong colours from the extremes of the colour spectrum. Contrast should be built by carefully using colour on muted or subtly-coloured backgrounds.

Coding/Cueing with Colour

- Colour can assist learning if used as a redundant cue (Durrett & Trezona, 1982).
- Colour coding can link logically related data; differentiate between required and optional data; highlight errors; and separate prompts, commands, and other elements in the interface (Adkins & Pease, 1991; Rambally & Rambally, 1987).

- Use commonplace denotations (red = danger, yellow = yield) (Adkins & Pease, 1991; Bailey & Milheim, 1991; Brockmann, 1991; Durrett & Trezona, 1982; Faiola, 1990; Faiola & DeBloois, 1988; Horton, 1991; Milheim & Lavix, 1992; Rambally & Rambally, 1987). Care must be taken to ensure that denotations are indeed shared, as some are culturally determined, such as the colours of political parties. Similarly, resultant "cultural connotations" may emerge, such as red denoting socialism, in turn connoting revolution (Wailer, Lefrere, & MacDonald-Ross, 1982). These denotations and connotations may not be shared by different cultures.
- Choose distinctive hue, brightness, and saturation differences for discrimination among major items. Poor colour memory may be overcome by carefully using colour to enhance discrimination (Faiola, 1990; Faiola & DeBloois, 1988).
- Ensure colour coding supports the task (Shneiderman, 1992).
- Have colour coding appear with minimal user effort (Shneiderman, 1992).
- Place colour coding under user control (Shneiderman, 1992).
- Be alert to common expectations about colour codes (Shneiderman, 1992).
- Use colour changes to indicate status changes (Shneiderman, 1992).

All of the advice about using colour for coding information emphasizes one simple principle: colour is one dimension of communication, and to exploit it well requires us to use it consciously and deliberately. Colour can be used to accomplish a wide array of instructional tasks, but it can also can also interfere with communication if it is used thoughtlessly or clumsily.

THE "SCIENCE"

There is a large and diverse body of empirical literature on the use of colour in screen design, but not all of it deals with instructional treatments. The review of empirical literature that follows eschews a considerable body of research on the use of colour on VDTs where the particular use seems quite different than would be found in instructional situations (e.g., air traffic monitoring, airline arrival/departure schedules, pilot/driver navigation systems, on-line job aids). This poses some risk, of course, as sometimes instruction and training approximate the situations we have chosen to ignore. Nevertheless, the danger of over-generalization seems greater than that of under-generalization, and we have chosen to present only the most generic conclusions.

Furthermore, we have reviewed here only that body of literature that claims to have specific relevance to VDTs. This leaves out a great body of research on the use of colour in instruction, conducted on media other than

VDTs (e.g., Dwyer, 1972,1978,1987; Fleming & Levie, 1993). We do not mean to imply that these signal works do not have relevance for multimedia screen displays, but that because that research was done on different media, we cannot be sure that generalizability is automatic (a point which is addressed later in the article).

Careful perusal of the articles listed in Table 1 which are empirical research studies or summaries of empirical research reveals three fundamental problems with the information base:

> Some of the advice that is promulgated from article to article may be obsolete, in the sense that the generalizations were formulated using equipment that has been superseded technologically.
> The nature of the task used in the research is not sufficiently similar to tasks typically performed during teaching and learning.
> The generalizations being passed on are either apocryphal in origin or else have been based on empirical results from different display media and transferred to VDTs on the assumption that, say, whatever was found to be an effect of colour when paper was the medium of display would automatically transfer to VDTs.

Possibly Obsolete Advice

A shortcoming of many of the published summaries of research on the use of colour in screen design is related to the rapid advance of technology. Generalizations based on studies employing obsolete equipment tend to be included in summaries of research alongside contemporary ones, although they may no longer be valid as a result oftechnological advances. For example, we examined the lists of references attached to the articles in Table 1, and counted the number of times certain articles were cited. The two most-often cited articles are in one case more than a decade old (Tullis, 1981) and in the other, two decades old (Christ, 1975). In the latter review, 75% of the articles reviewed were written in or prior to 1971,50% of them were written in or prior to 1965, and 25% of them were written in or prior to 1960. Thus the widespread citing of Christ's conclusions promulgates what may be some dubious, aging generalizations.

Age alone does not necessarily invalidate generalizations, but one has to wonder whether the results of investigations conducted on the hardware available in the 1960s or 1970s or even the 1980s really has currency in today's rapidly shifting technological world. For example, the rapid emergence and widespread dissemination of high resolution, many-bits-deep colour monitors throws into question generalizations derived from studies conducted on relatively coarse-grained monitors capable of displaying only six or eight colours. Today, sixteen-bit colour is fairly common, and many systems sport twenty-four-bit and thirty-two-bit colour. In addition to the greater number of hues these systems make available, they afford much more control over saturation and, therefore, contrast, which has been shown to have considerable importance (Adkins & Pease, 1991; Baker, Belland, & Cambre, 1985, 1986; Faiola & DeBloois, 1988; Mills & Weldon, 1987; Pace, 1984; Radl, 1980; van Nes, 1986). Given that the human eye can distinguish many different colours and that we are capable of providing many thousands of different colours on commonly-available VDTs, how useful is empirical evidence about the optimality of a given colour of text on a given colour of background, given that the research was conducted on equipment capable of generating only eight colours? Unless the colours involved are described in a much more specific fashion (e.g., Munsell colour system coordinates, or RGB values) than has been done to date, little useful knowledge obtains.

As another example, consider the widely-promulgated advice that navigation elements of a screen be consistent in placement and type, a notion that appears to be much more experientially derived than empirically. Consistency may still be good advice, but given that the generalization was derived primarily on the basis of experience with mainframes that were character-display and command-line or text-menu-based, one wonders how rigidly to apply that advice to a graphical user interface with hypertext capabilities. To take a more extreme example, some of the literature contains advice that is plainly obsolete (e.g., "use character sets with true descenders").

What this means, then, is that instructional designers must learn to pay close attention to the dates when research was conducted, and attempt to ascertain the currency of the equipment used, before accepting generalizations as guides to their efforts. By the same token, researchers and authors of literature reviews should be sensitive to the issue, and make the reader aware when generalizations might no longer be valid.

The Nature of the Task

Another shortcoming of many of the published summaries of research on the use of colour in screen design is they do not take into account the type of task used in the research being summarized, hence both instructional and non-instructional uses of colour in screen displays are lumped together in recommendations for practice. Results of studies conducted in pursuit of improved air traffic control systems are sometimes mixed in with others to set the stage for an experimental procedure in education, or are offered by reviewers as purportedly relevant to instructional practice. But are they? A careful analysis of task demands seems warranted.

We classified recent empirical studies according to whether the nature of the task employed was similar to instruction. Only about one third of those employed tasks that were clearly similar to instruction; about one-sixth were classified as "maybe" instructional (meaning that arguments might be made for them, or that it was not possible to tell from the description what the task was). The remaining half of the studies used tasks that were not related to common instructional activities. Clearly, at minimum, great caution must be used when generalizing the results of the third group to instructional situations.

TABLE 2
Tasks Employed in Recent Empirical Research

Task Type	Task Description
Clearly Instructional	· CAI teaching mathematical rule for average speed (ani mation) (Baek & Layne, 1988) color cueing in geometry lesson (Hativa & Teper, 1988) · selecting colour combination preference (D'Angelo, 1991) · oral reading and rating of comfort (Simmers, 1988) · locating facts in materials previously read (Wright & Lickorish, 1988 [1]* , Wright & Lickorish, 1988 [2]) · reading from a screen for rate and comprehension (Claiming & Schmitt, 1989, 1990)
Maybe Instructional	· recognizing a color picture of an object presented on a monocrhome display (Baker, Belland, & Cambre, 1985*, Baker, Belland, & Cambre, 1986**) searching through menus to locate a specific page of information (Kerr, 1987) reading information from one part of screen and input ting it on another (Pace, 1984 [2])
Clearly Non-Instructional	- operating a fast food cash register with a keyboard-like layout (McDonald, Molander, & Noel, 1988) • searching for nonsense words (Pace, 1984 [1]) • counting frequency of random target letter (Anglin & Towers, 1993; Ohlsson, Nilsson, & Ronnberg, 1981) • "Concentration" game with alphabets (Livingston, 1991) • transcribing letters shown on the screen and identifying number flashed on the screen (Radl, 1980[1], [2]) • naming the color of small moving squares appearing on the screen (Radl, 1980[3]) • detecting and naming color of a moving square on a colored background (.Radl, 1980[4]) • rating preference for color combinations (Holcomb, 1991; Pastoor, 1990 [1]) oral reading of nouns in random order; locating target word in list of similar words; rating preferences (Pastoor, 1990 [2]) speed and accuracy of interpreting schematic in trouble shooting problems on telephone lines (Tullis, 1981) identifying letters and digits flashed on a screen (Bruce & Foster, 1982)

* Some papers report more than one study. In this table, multiple studies by the same author(s) are designated with numerals in square brackets.
** These two papers appear to report the results of the same study.

Table 2 classifies recent empirical studies according to task employed.

Research methods for studying colour in screen design are subject to the same debate that has flourished since nonsense syllables were first used to investigate processes of learning: How important is it that the tasks employed in research studies approximate real life? Is it better to risk confounding from the content or instruction, or to employ a task that is "content-free"? The current consensus seems to be that a high degree of similarity between a research task and real life is essential. That fact seems to have been glossed over in some of the recent research on colour in screen design.

Different Display Media

Another problem centres on studies involving colour that were conducted on media other than VDTs. While the results of such studies may, in fact, be valid for VDTs as well, there is reason to be cautious in making the generalization. For example, it has been shown that reader preferences for fonts in printed materials are quite consistent (Misanchuk, 1989a; Tinker, 1963, 1965). However, users prefer quite different fonts on computer screens than they do on paper (Misanchuk, 1989c). There is also some indication that leading (vertical spacing of text) on paper and on a VDT might show similar differences (Misanchuk, 1989b). Might colour effects and preferences suffer similar changes in response to changed display media?

Furthermore, CRTs are radiant light sources, operating on the additive colour system, while traditional colour theories are based primarily on reflected light, using the subtractive system. It is a qualitatively different experience to view text or images on paper and on a VDT, and "[artists] are discovering that certain aspects of colour theories used in traditional art media are not applicable to computer graphics" (Collery, 1985, p.1).

What Has "Science" Taught Us About Colour?

To determine what we really know-from empirical evidence-about the use of colour for screen design of instructional materials, we examined those empirical studies that employed tasks that were identified in Table 2 as either clearly instructional or maybe instructional.

Table 3 summarizes those studies into four categories, representing those that:

- showed no significant difference;
- indicated user preferences;
- possibly showed a negative effect; and
- may have restricted generalizability because of special characteristics of the subjects or the hardware used.

Holcomb's study used only five colour combinations (hence did not cover the complete range of possibilities), tested only for preference (hence efficacy is unknown), and involved subjects with special characteristics (over age 40).

TABLE 3
Summary of Empirical Research Studies

Category	Author(s)
No significant difference	Baek & Layne, 1988 Clausing & Schmitt, 1989 Clausing & Schmitt, 1990 D'Angelo, 1991 Kerr, 1987
Preferences identified	Holcomb, 1991
Possibly negative results	Wright & Lickorish, 1988 [1] Wright & Lickorish, 1988 [2]
Possibly restricted generalizability	Baker, Belland, & Cambre 1985* Baker, Belland, & Cambre, 1986* Hativa & Teper, 1988 Simmers, 1988

*These two papers appear to report the results of the same study.

Wright and Lickorish used fairly rudimentary equipment by today's standards (a Z-80 machine with an 80-column by 32 row display). Their major finding was no significant difference in reading time, but there was some evidence that gains resulting from practice at the task were smaller for the colour-cuedversions than for non-colour-cuedversions, hence they speculated that the colour cues may have interfered. Baker, Belland, and Cambre use Apple II low-resolution graphics, which are also quite rudimentary by today's standards. Hativa and Teper's use of a computer as an "electronic chalkboard' is not one that immediately springs to mind when one talks about using computers for instruction. Is it safe to generalize their findings to screen design? Simmers' subjects were partially-sighted, hence his results may not generalize to the larger population.

So, what do we know from the "scientific" literature about the use of colour in screen design for instruction? Clearly, not much. There is an obvious need for considerable research to be conducted in the area of using colour in the design of screen displays for instruction.

Generally speaking, we place high value on the results of empirical research, even while recognizing that empirical research may not be capable ofproviding all the answers, and that research results are coloured by the way in which the research was conducted. At this stage, it appears that opinion, myth, and legend may inform instructional screen design practice more than science. Hopefully, this review will serve as a wake-up call to researchers about the need for more investigation into an area in which it may seem, at first blush, we already know a good deal.

A CALL FOR FURTHER RESEARCH

One level of research required is merely the replication of the best of earlier studies, on newer technology, and with more attention to reporting specifics of that technology. We need to test conclusions in light of improvements in display technology. For example, do earlier findings of "good" and "bad" (however they are defined) combinations of text on backgrounds hold when de-saturated colours are employed? Both propositions derived from physiological research (Murch, 1984) and experiential advice (e.g., Faiola, 1990; Faiola & DeBloois, 1988, among others) would lead one to conclude that de-saturated colour, especially for backgrounds, is preferable to saturated colour, but we have been unable to locate any research in which this hypothesis was tested in an instructional situation. (Our own observations have led us to speculate that beige or light gray might form the most pleasing and effective background against which to present text, for example, but we have not yet subjected that speculation to empirical verification.)

On another level, we now have the technological wherewithal to go beyond static displays on VDTs; we need to recognize that emerging multimedia technologies introduce new questions. What is the role played by compressed colour video in displays? How can colour be used effectively to present animated graphics? How do various compression strategies influence colour? Does colour really motivate, as is often claimed, or does it interfere and distract, as has also been alleged (Brockmann, 1991; Rubens, 1986)?

The number of possible research questions involving the use of colour in screen design for instructional purposes is very large. In investigating any of them researchers would do well to ensure that their tasks are relevant to the population to which they hope to generalize, that the equipment used is fairly contemporary, and that they provide a great deal of technical detail (with respect to that equipment and the way in which it was used) when reporting their results. Prospective summarizers of research should also keep these imperatives in mind when teasing out generalizations. Finally, instructional designers seeking to apply generalizations to their work should act as a second level of filtering, by once again checking to see that the imperatives were applied at earlier stages.

TOWARD A CONNOISSEURIAL APPROACH

The literature does not favor either an exclusively scientific or a non-empirical treatment of screen design. On the one hand, we have the "art" literature, which offers empirically unsubstantiated and sometimes conflicting advice, traditions, and opinions; on the other, the "science" literature, which when examined critically is reduced to providing little useful guidance to designers of multimedia screens for instruction. Neither empiricists nor artists can find much comfort in the current state of affairs.

To consider screen design as a bipolar issue with rational and creative emphases at either end of the spectrum creates a false dichotomy. We favor a connoisseurial treatment where science and experience both have value and can contribute to a rich understanding of how screens can be designed for multimedia presentations. Aesthetically pleasing multimedia can employ scientifically derived principles of instructional design, and well-designed instruction can be creative and aesthetically pleasing.

One way to approach the convergence of science and opinion in screen design is through a model of connoisseurship. A connoisseur has a refined set of skills and principles for making judgments. Belland (1991) discussed four critical aspects of performing connoisseurship. First, a connoisseur must be able to make fine discriminations; that is, perceive differences and elements that are too subtle for unschooled individuals to notice. Next, the connoisseur develops an hierarchical system of concepts for making judgments. Systems of key ideas and subordinate notions are developed, even if not articulated to others. Third, principles are developed to describe the structure of relationships among concepts. Finally, a connoisseur develops strategies to focus on salient aspects, and ignore less important aspects of the item being judged.

A connoisseurial approach, with its emphasis on complexity and fine discrimination, lends itself well to multimedia design. In sophisticated multimedia productions, designers are concerned with a combination of technical, aesthetic, and narrative issues in which colour might play a role. How, for example, might colour be used to convert a dramatic scene to a comedic scene? How might colour act as a metaphor for emotions such as joy, anticipation, or contentment? How can colour be used to convey elegance or sophistication?

Clearly, to develop a connoisseurial appreciation for multimedia, one must be informed about both science and art, in both senses of both words. In developing the notion of connoisseurship, Belland (1991) further argues that an individual's involvement with a work must be extensive and intensive. A connoisseur draws on a broad body of knowledge and experience which allows the work being examined to be interrelated with other significant works. It is also important for a connoisseur to give attention in an analysis to those elements which are important (ignoring or downplaying trivial elements), and to reflect on the meaning of the new experience. Judgments are made within a context of acquired knowledge, taste, and experience, and aesthetic judgments are amalgams, not precise articulations of specific rules.

CONCLUSION

We ask you to consider the entirety of the above advice within the contexts of projects, not as a set of generalizable principles. Consider your project and its design as whole cloth rather than a series of micro-decisions to be made. "Design quality and consistency grow from a coherent set of ideas, not from personal taste or committee compromises, not from the baggage of past user interfaces, not from the ad hoc reasoning about each little part of the computer screen" (Tufte, 1992, p. 15).

One can extract guidance on the use of colour exclusively from the empirical literature or from less rigorous sources, but peril lurks in both camps. We need more and better studies about colour in screen design to be sure, but we also recognize the value of judgement, common sense, and a refined connoisseurial sensitivity.

Given the literature we have reviewed, we conclude with the single best piece of advice about using colour we have found:

> **"Above all, do no harm."** (Tufte, 1992, p.16)

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