Colour Science for Colour Design

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ABSTRACT

In this paper I will extend the meaning of 'colour science' to embrace all kinds of knowledge about colour, however derived, that can be useful to designers. Successful colour design depends on knowledge as well as on the designer's natural gifts and experience. Knowledge can shed light on aspects of colour that are confusing, it can help designers to avoid mistakes, and it can reveal a range of new possibilities. I will demonstrate the value of colour science for colour design with some examples of what can be learned from other disciplines as well as from design itself.

1. INTRODUCTION

'I cannot really think of a more fascinating subject of study or one which spans such a wide spectrum of knowledge.' Those are the words of W.D. Wright (1967, p vii), one of the giants of colour science and the first president of the AIC. One of the most rewarding aspects of my own involvement with the AIC has been the opportunity to meet and learn from people who work in disciplines other than my own. I find colour science intrinsically fascinating, but I also believe in the value, for colour design, of having a wide range of knowledge.

The idea of 'colour science' may be limited in some minds to those aspects of colour that are dealt with by 'scientists'. Here I want to extend the idea of science to include its old meaning in Middle English where 'science' simply meant 'knowledge of any kind' (Thompson 1995, p 1236). Useful knowledge about colour for designers certainly comes from physics, chemistry, physiology, and psychology, but it also comes from philosophy and from design itself as well as from the visual arts in general. In this presentation I will make a rapid tour of the field as a kind of sales pitch to encourage further study.

2. THE 'COLOUR CLUSTER'

It is appropriate to begin with philosophy. Once you ask the question 'What is colour?' you open the door to a world of new possibilities. It becomes clear that the 'colours' that physicists measure are not the same kind of thing as the 'colours' that psychologists study or the 'colours' that artists brush onto paper or canvas. For me, this realisation was the key to overcoming all kinds of confusions and misunderstandings. In a separate paper at this conference I propose that there are eight different kinds of thing that can be identified as 'colours' and that the means used to identify a colour determine what kind of thing it is that is being identified (Green-Armytage 2005). The main distinction is that between colours as objective physical properties and colours as subjective visual experiences.

Philosophers are divided over whether colours are to be regarded as objective or subjective, but for designers I think it is more useful to regard them as both. In the expanded edition of his book *Color for Philosophers* C.L. Hardin (1993/1998) suggests that (p xix):

> What is required is a careful examination of the various components of the 'color cluster' and just how they relate to each other. A proper full-blooded account of color would include the respective roles of the phenomenology of color perception, its biological substrate, the evolution and ecology of color vision, the color-relevant properties of physical materials, the

> affective, aesthetic, and communicative dimensions of color, the relations that colors bear to each other, and the uses of color language.

Psychologists, physiologists, biologists, ecologists, physicists, chemists, sociologists, anthropologists, artists, designers and linguists would each claim expertise in a component of Hardin's colour cluster. I will use those components as headings for what follows:

2.1 The Phenomenology of Colour Perception

For most people, and certainly for designers, it is colours as phenomena of visual experience that ultimately matter. It is through how they appear that colours convey meaning and stir our emotions. That being the case it is most helpful for designers to work with a model of colours as visual phenomena such as the *Natural Colour System* (NCS). Other systems that designers use, such as the *Pantone Matching System* for printing inks, model colours as physical substances. The Pantone colours are arranged according to ink mixing formulae. It is helpful to be able to see, in the *Pantone Formula Guide*, what a particular mixture of inks will look like. The appearance of such a mixture can then be located in an appearance model and described in terms of the NCS.

A given ink mixture will not always look the same. This can be due to changing lighting conditions or the effect of simultaneous contrast. Rather than call this an illusion it is more useful to recognize that colour as a physical substance is one thing and colour as a visual experience is something else. When designers work with inks or paints they are manipulating physical substances to achieve particular appearances. Knowing that the appearance of a substance can be altered by the context in which it is seen can help designers avoid mistakes. They can also use that knowledge to their advantage. Sydney Harry used his knowledge of contrast effects to achieve a rich design for a carpet where the number of separately dyed yarns that could be used was limited.

2.2 The Biological Substrate of Colour Perception

The mechanism of colour vision is still not fully understood. Rolf Kuehni refers to 'a black box into which biologically produced correlates of physical stimuli disappear and out of which color experiences appear.' (Kuehni 2003 , p 15). We know about cone cells and opponent processes, and we know that the responses of the three cone types represent the first stage, and opponent processes a later stage, in the chain of neural activity leading to the perception of colour. But then comes the black box.

Ewald Hering worked in the opposite direction, using the phenomena of visual experience as his starting point. He identified six 'Elementary Colours' – White, Black, Red, Green, Yellow, and Blue – and argued that they must have physiological counterparts (Hering 1964/1920, p 106). At first it was tempting to see these in the opponent processes. Hering's Elementary Red, Green, Yellow and Blue, as visual phenomena, are recognised as 'unique hues', but Arne Valberg points out that 'no unitary physiological processes that correlate with unique hues has yet been discovered.' (Valberg 1998, p 150).

For designers it would be good to know exactly what goes on inside Kuehni's black box. Knowing how physical stimuli are transformed into colour experiences might give designers new insights and suggest new possibilities. Meanwhile the status of the unique hues remains. They play an essential role as conceptual reference points in the NCS model of colour appearance.

2.3 The Evolution and Ecology of Colour Vision

Colour vision evolved in animals because, as Daniel Dennett suggests, 'some things in nature "needed to be seen" and others needed to see them, so a system evolved that tended to minimize the task for the latter by heightening the salience of the former.' (Dennett 1993, p 377). Hence the co-evolution of flowers and insects, fruit and monkeys.

Nature represents an ideal source of knowledge for designers on how to make best use of colour. However, the ease with which we are now able to change the colours of things, and the arbitrary way in which colours have increasingly come to be used, has prompted Nicholas Humphrey to express concern over what he sees as a 'debasement of the colour currency'. (Humphrey 1976, p 96). Humphrey urges designers to study the ways in which colour enhances our ability to relate to the natural environment and to use that knowledge as a guide to the use of colour in the cultural environment. He points out (p 98) how, in nature, colours act as signals to attract attention, convey information and affect emotions.

Knowledge of how colours work in nature helped Curtin University Design student James Rogers solve a design problem with seemingly contradictory requirements: a litter bin for a national park. The bin should be visible and invisible at the same time. Rogers used camouflage colours to hide the bin itself while drawing attention to its presence with a small 'flag' in a highly chromatic colour, like a flower.

2.4 The Colour-relevant Properties of Physical Materials

In everyday situations it is the patterns of radiant energy entering the eye which are the stimuli for the perception of colours. The energy can come directly from a source such as the sun, a candle flame or a neon sign. It can also come to us second hand, as it were, after an encounter with something solid, liquid or gas. Under the latter circumstances the pattern of energy that reaches our eyes is determined by the energy that leaves the source and what happens to that energy on the way.

For a designer the most useful information is the spectral composition of the light before its interaction with matter and the properties of the matter itself whereby it absorbs, transmits and reflects the different wavelengths. It is possible to establish the spectral radiation profile of a light source as well as the spectral transmission and reflection profiles of a material. A spectral profile is a guide to the colour rendering property of a light source. This is important information for designers who have to specify lighting for particular purposes. Paints, inks and dyes are used to change the spectral reflection profile of a surface. W.D. Wright's account is very simple: 'The colouring power of a dye or pigment is nothing more and nothing less than the power to reduce the energy in certain parts of the spectrum relative to the rest.' (Wright 1969, p 46).

Spectral profiles can be established by using a spectrophotometer. The same instrument can also be used to establish 'chromaticity co-ordinates' which pin-point a position on the chromaticity diagram for a light source or surface. If two surfaces are shown to have the same co-ordinates it means that they would be judged a match when seen under the specified light source by a 'standard observer'. In that sense they would be 'the same colour', but they might have different spectral profiles. This means that they would be 'metameric' and might not match when seen under a different light source.

Designers certainly need to be aware of metamerism. Metamerism has been described by Roy Berns (2000, p 27) as 'both a blessing and a curse'. It is a blessing because it makes it possible to reproduce the colours of things in a photograph and on television. It also makes it possible to match the colours of different materials, such as plastics and textiles, and to produce paints that match where different pigments are used. It is a curse when a colour match breaks down. A mismatch can be a very serious matter in a commercial situation. The designer who specified the offending paints or materials is not likely to earn any sympathy by pleading ignorance.

2.5 The Affective, Aesthetic, and Communicative Dimensions of Colour

Aesthetics and communication would be claimed as their domain by artists and designers. They could argue, with some justification, that a good source of knowledge about colour is their own experience of using it, but I do not agree with those who are content to leave it at that. Nor do I agree with those who rely exclusively on their own judgements when they choose colours to convey particular meanings. Their intuitions might be sound, but research is a surer way to obtain knowledge about how people will respond to particular colour combinations.

Designers can turn to published results of research into colour meanings and emotional response to colour, as it has been conducted by psychologists, notably Lars Sivik (1976) and Shigenobu Kobayashi (1981). They can also conduct research of their own. Group studies are particularly valuable in that they reveal differences of opinion and response. Such studies can also lead to an understanding of how the intended users of designed objects and spaces are likely to respond so that appropriate materials, paints or inks can be specified. Students of Design at Curtin University have explored colour meanings in an exercise, modeled on one devised by Wendy Alford, that amounts to a re-invention of Kobayashi's *Color*

Image Scale. While our exercise is comparatively superficial, we have reached much the same conclusions as Kobayashi.

2.6 The Relations that Colours Bear to Each Other

Colours can be similar to each other in some respects while being different in others. The ways in which colours are related to each other depend on the kinds of thing that the colours are understood to be. If colours are understood to be physical properties, relationships could be seen in terms of chemical composition or spectral profile. The same pigments might be present but in different concentrations, or the spectral profiles might have peaks at the same dominant wavelength but one peak might be higher than the other.

Colours as visual experiences can also be related in a number of ways and it is these relationships that are of most concern to designers. With the unique hues in place as reference points, a colour's own hue can be judged in relation to those points. Since there is a high degree of consensus about the appearance of the unique hues themselves there can be a similar consensus in judgements about other colours, such as a turquoise that might be judged to be slightly more bluish than greenish.

Two paints, one a pale and the other a deep turquoise, but both appearing slightly more bluish than greenish, might be made up from the same pigments or have spectral profiles with the same dominant wavelength. Physical characteristics are certainly related to appearance characteristics, but they are not the same thing. Two surfaces that have a particular physical characteristic in common will not necessarily have corresponding appearance characteristics in common.

To use colour effectively designers need a good grasp of the various dimensions of colour appearance. Apart from an appreciation of the dimensions of hue and chroma or chromaticness, designers need to understand how colours relate to the steps of the grey scale. A colour's 'grey partner' can be determined by finding the step on the grey scale where the border between the grey and the colour is least distinct. Colours with the same nuance that is with the same whiteness and blackness do not necessarily have the same grey partner. A grey scale, in the form of a 'lightness metre', is produced by the Scandinavian Colour Institute and is the best kind of tool for finding grey partners.

2.7 The Uses of Colour Language.

With different possible meanings for the word 'colour' itself it is not surprising that colour language has become a minefield. Communication can go astray within and between the different groups who work with colour. For example, those who use the NCS understand 'hue' to mean relative resemblance to the unique hues (Hård & Sivik 1981, p 136), while those who use the DIN system understand 'hue' to mean dominant wavelength (Richter & Witt 1986, p139). 'Lightness' is understood by some to mean overall light reflectance, by others to mean degree of resemblance to White (Green-Armytage 1983). It is an advantage for designers to be aware of such differences.

Words are tools for thinking as well as for communication. A larger and more sophisticated vocabulary in relation to the phenomena of visual experience would increase a designer's capacity for thought. As Ezio Manzini puts it (1989, p 18) 'Every new word acquired is a glimpse of the possible.' An attentive look at the visual world can reveal gaps in our vocabularies. A journey through colour space, starting at White, can take us via pink, Red, and orange to Yellow, with a detour to brown. A similar journey can take us via Green to Yellow, but the colours on that journey that would correspond with pink, orange and brown would all be called 'green' in spite of clear differences in appearance.

3. KNOWLEDGE AND UNDERSTANDING

Knowledge can shed light on aspects of colour that are confusing, it can help designers to avoid mistakes and it can reveal a range of new possibilities. In the brief time left I will show how knowledge can help resolve the confusions attached to two concepts that feature prominently in what I call 'traditional art school colour theory' (Green-Armytage 1995, p 191): the concepts of primary and complementary colours. I will finish by showing how concepts that appear to be contradictory can be accommodated in a colour space that is elastic.

3.1 Primary Colours

Conflicting concepts about the nature of colour are evident in the case of the so-called 'primary colours'. To illustrate how the meaning of 'colour' changes within each of these supposedly authoritative definitions I will follow Karin Fridell Anter by adding the words 'physical' and 'visual' in brackets (Fridell Anter 2000. p 30). In *The Color Compendium* '… primary colours (visual) are ones that cannot be mixed or formed by any combination of other colours (physical)' (Hope & Walch 1990, p 253). In *The Concise Oxford Dictionary* a primary colour is 'any of the colours (physical) … from which all other colours (visual) can be obtained by mixing.' (Thompson 1995, p 1085).

I have elaborated on the confusions inherent in these definitions elsewhere (Green-Armytage 1995). I have also shown how physical and visual primary colours can be brought together to help designers manipulate physical processes to achieve desired appearances (Green-Armytage 2003). The appearance of the process inks magenta, yellow and cyan can be plotted in NCS space together with the appearance of their mixtures. The mixture lines define the gamut of appearances achievable with that process.

The way that colour names are used for a range of different hues adds further confusion to that which already exists between additive mixture of lights and subtractive mixture of inks and paints. Although a bit bluish, magenta still comes within the range of 'reds', while the 'red' of additive mixture is clearly yellowish. Use of the single word 'red' diverts attention from the more fundamental difference between two distinct physical processes. Red as a unique hue serves a double purpose in traditional art school theory. It is regarded as one of the 'colours' from which other colours can be mixed; it is also used as a conceptual reference point.

3.2 Complementary Colours

'Complementary' colour pairs have been defined as mixing additively to white or subtractively to grey-black (Itten 1970, p 20). They also appear as each other's after-images and are regarded as a key to colour harmony (Goethe 1970/1810, p 317). Each definition supposedly yields the same pairs but experiment shows that this is not the case (Green-Armytage 1996).

If complementary colours are to be placed opposite to each other on a colour circle, the circle must be variously stretched and compressed to bring the differently defined pairs into position. If the colour circle is to be used as basis for a 'harmonious' composition a decision will have to be made about which circle to use. If the circle is to be used as an indication of the likely result of mixture, the choice of circle will depend on the kind of mixing.

3.3 Elastic Colour Space

An elastic colour circle, which can be stretched and compressed to reveal different relationships, can be used to show how additive and subtractive mixtures of the 'same colours' can yield such radically different results. A paint that appears yellow and one that appears blue can be painted on either side of a disc and can also be mixed together in the palette. When mixed in the palette the result appears green, but when the disc is spun at high speed it appears pink.

A cross section of colour space can also be stretched and compressed. In one configuration it is easy to see a colour's nuance, its relative whiteness and blackness. In another configuration it is easy to see what a colour's grey partner would be. In effect, the colour space of a system like the NCS can be 'morphed' into that of a system like Munsell.

4. CONCLUSION

There are certainly many designers who are naturally gifted and have a flair for colour, but I am not happy with Johannes's Itten's suggestion when he writes 'If you, unknowing, are able to create masterpieces in color, then unknowledge is your way.' (Itten 1970, p 7). However gifted, designers can still make mistakes and miss opportunities. I prefer the words of another educator who is also one of the most gifted colour designers I know, Grete Smedal. In her account of the course she was teaching in Bergen, Norway, she writes (Smedal 1983, p 5):

> It is perhaps just here that we find the most important objective of colour theory: that of expanding consciousness. Knowledge must not inhibit creativity, but must open eyes and expand horizons, so that the tool which colour forms can be of service in evoking an image, or in product or environmental design.

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