Before colour theory – learning to discriminate, describe, and order colours

Paul Green-Armytage and Maggie Maggio*

Curtin University, Perth, Western Australia
**Portland, Oregon, USA*
Emails: p.green-armytage@curtin.edu.au; p.green-armytage@aapt.net.au

From infancy, young children will experience a wide range of colours in their surroundings. The richness of these experiences can be diminished when they are first taught about colour. They are taught colour names, the order of colours in the rainbow, the concept of primary colours, and the association of colours with emotions. In each case the focus is on vivid colours only. This article is focused on an alternative to early colour education which begins with learning how to discriminate and describe colours in all their variety – not just the vivid colours but pale, muted, and dark colours as well. This first step is followed by activities exploring the attributes of colour in two dimensional exercises and then building three-dimensional colour models. All the activities are designed as 'scaffolded' steps toward understanding and visualising the relationships of the colours to each other. We argue that a well-developed awareness, combined with a framework for ordering and describing colours, should be in place before the introduction of more formal aspects of colour theory.

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Introduction

Our central concern here is how best to introduce the topic of colour in early education. We propose that young children need first to develop their ability to recognise the subtle differences and relationships between colours from which they can build a concept of what we are calling the 'colour universe'. This is not a term in current use. We use the term 'colour universe' to fill one of the voids in the language of colour that we have identified [1]. It is possible to think of a seamless continuum of colours in a kind of cloud with colours getting paler towards the top, darker towards the bottom, more vivid towards the outside of the cloud and more muted towards the centre. Individual colours have their places within this cloud, and relationships can be plotted. But at present there is no single definitive term in general use that encompasses all the colours that we can perceive or imagine.

Having a concept of the colour universe should be a prerequisite before the introduction of other aspects of colour theory such as those that are concerned with the mixture of paints to produce other colours, or guidelines for producing harmonious colour combinations. In this we are following Josef Albers where he "places practice before theory" [2 p.1] and where he writes [2 p.2]: "What counts here – first and last – is not so-called knowledge of so-called facts, but vision – seeing."

We focus on the relationships between what we see and the words we use to describe what we see. When children are first taught to name colours, the names themselves can have the effect of limiting what they actually perceive. When a single colour name is used to describe a wide range of different colours those different colours can come to be regarded as being all the same. Another limiting effect comes from the way an introduction to colour for young children is typically focused on vivid colours as seen in the rainbow, the spectrum, and the traditional colour circle. This leaves out the very large number of other colours – the pale, dark and muted colours – that are dominant in our surroundings.

We argue that an expanded vocabulary of colour names, linked to a model of colour relationships that goes beyond the two-dimensional spectrum and colour circle, can help children to build a more complete concept of the colour universe. With such a concept in place students can then determine the usefulness or otherwise of the various aspects of colour theory as they are introduced in later years.

As part of the Joint ISCC/AIC Colour Literacy Project we have developed a basic three-dimensional model with 36 colours that are identified by a simple system based on nine hue names. In addition to these 36 chromatic colours, we have a nine-step grey scale from white to black. We have applied these colours to sets of tiles that can be used in various sorting exercises. Children can sort the tiles into family groups where a pale, a dark, a vivid, and a muted colour all have the same hue. These hue families can then be arranged to form a three-dimensional model. We have tested the sorting set with groups of volunteer teachers who are giving us feedback on how these tiles might be used in the classroom and how children at different stages of their education might respond.

In this article we begin with a brief account of how babies and toddlers can be encouraged to look closely at the colours in their environment and so build a solid foundation of experience. We explain how colour names and models of colour relationships are currently introduced and draw attention to the limitations of the concepts that are formed as a result. We describe our sorting set and explain the rationale behind our choice of colours. We introduce the terms that we use, some of which are new. We explain how the colour tiles have been used in various exercises in the workshops for the volunteer teachers and we follow this account with illustrations of the same exercises which were carried out online using a digital version of the sorting set. We show how the colours of the sorting set can be organised in a three-dimensional model and conclude by showing how the colours of the sorting set can be linked to the colours of everyday objects.

We should point out that we have limited our project to the way that colours and colour relationships are described in English. This article is essentially a progress report, and we welcome further comments and suggestions.

The beginnings of colour education

Learning to look closely at colours

The home is the first 'classroom' for colour education and parents and caregivers are the first 'teachers'. Their important role is to provide a stimulating environment that will help infants learn to perceive colours in all their variety. Infants can also be encouraged to look closely at objects at home and in the garden (Figure 1). When young children start to walk the 'classroom' for colour education

can be expanded and the 'teachers' can play a more active role. Toddlers can be taken for walks and encouraged to look closely at the things they encounter (Figure 2).

Figure 1 (left): Drawing attention to the different colours of leaves.
Figure 2 (right): Looking for little fish in the lake.

Young children can collect things like fallen leaves (Figure 3). Pebbles and seashells from the beach can be arranged in order (Figure 4).

Figure 3 (left): Looking at the fallen leaves.
Figure 4 (right): Arranging a collection of pebbles and seashells.

These activities can be enriched as a toddler begins to talk. The parent or caregiver can draw attention to particular things and suggest, for example, that they collect such things as fallen leaves that can be arranged in some kind of colour order when they get home. The artist Bridget Riley [3 p.22] tells how, when she was a young child, her mother took her for walks: "She was always pointing out colours: in

the sea; the sparkle of dew; changes of colour when the dew was brushed away. … She wasn't a painter, she was a 'looker'".

Occasional magic

Every opportunity should be taken to enrich a child's life by visits to places like museums and the zoo. Occasionally there will be a special event such as the installation of *Luminarium* during a children's festival in Perth in 2010 (Figure 5). As they walked through the space children could experience the effect of changing light as it was filtered by translucent panels in the plastic structure. Another way to introduce the science of colour is with giant bubbles (Figure 6). *Science Sparks* [4] is one of several sites on the Internet with instructions for making the mixture of water, dish-washing liquid, and glycerine that can be used to produce the large bubbles.

Figure 5 (left): Inside Luminarium *at the* Awesome Festival *for children in Perth, November 2010.*
Figure 6 (right): Large bubbles produced with a mixture of water, dish-washing liquid, and glycerine.

From visual experiences to the formation of concepts

Before they can talk, young children can have a wide experience of seeing different colours in their environment. As they begin to talk they can build on this experience to develop a rich conceptual framework of colours and colour relationships. But language can be a two-edged sword. Words can help children to form concepts but the concepts that are formed can be constrained by limitations in the language. Concepts can be further constrained by the way that the topic of colour is introduced. For many children, *Crayola* crayons are the first medium they are given for producing coloured drawings, but the range of colours that can be produced with the basic set of 24 crayons is very limited. There is a strong emphasis on vivid colours with very few that are pale, dark, or muted.

The current beginnings of teaching about colour

Early learning about basic colour categories

As young children begin to talk it is possible to begin more active teaching about colour by connecting experiences to words.

Many young children are introduced to colour terms through books. These first books are highly durable with pages that are cloth or cardboard. Some of these could be described as the first textbooks

and they introduce young children to some basic concepts and categories. Colour is a common topic, and it is from such books that many children are taught to name colours. It is books like these that can have the effect of narrowing a child's awareness of the range of colours around them. Maggie Maggio has a very large collection of these books and has found that almost all of them limit the number of named colours to the eleven so-called basic colour terms identified by Brent Berlin and Paul Kay [5]. These terms are: White, Black, Red, Green, Yellow, Blue, Brown, Purple, Pink, Orange, and Grey.

Using an array of 330 colours (which included white, black and eight greys) Berlin and Kay asked speakers of different languages to indicate the ranges of different colours that they would identify with each of the basic terms. Paul Green-Armytage [6] used Pantone chips to construct a layout of colours similar to that used by Berlin and Kay. He asked his 'research assistant', his three-year old daughter Emily, to name each of the 144 colours in the array. It turned out that she was the ideal person for this task. At that time, her vocabulary of colour names was exactly the eleven basic terms. She did not know other common colour names like turquoise and olive and it did not occur to her to use composite names like bluish-green. Furthermore, she had great patience and willingly named every colour. Her pattern of naming is shown in Figure 7.

Figure 7: Layout of colours on a similar pattern to that used in their research by Berlin and Kay. Borders between groups of named colours established by a three-year old.

Emily's pattern of naming is very similar to that plotted by Berlin and Kay for speakers of English. A significant feature of the data from this research is that the number of different colours named by the different names varies greatly. There are very many more purples, blues, and greens than there are yellows, oranges, and reds. This means, for example, that all the different greens that young children will have experienced – in the park, the shops, and on their dinner plates – are all now collected under a single name so that they become, in effect, a single colour; they are all just 'green'. This can have the effect of blunting a child's sensitivity to the subtle differences between the many different greens, but it can also mean that they do not recognise that there are other meaningful ways of categorising colours as 'pale', 'dark', 'muted' and 'vivid'.

Early learning about the science of colour

Other books for toddlers in Maggio's collection focus on the rainbow. Children may be introduced to the colours of the rainbow as seen in the spectrum and have these colours revealed with the aid of a prism as shown in Figure 8A.

Young children are often taught that there are seven colours in the spectrum: red, orange, yellow, green, blue, indigo, and violet (ROYGBIV). But if you look at a spectrum you can see that there are no hard borders separating the colours. Red does not change abruptly to orange; the spectrum is a continuum. You can see orange between red and yellow, but you can also see lime between yellow and green and turquoise between green and blue. (Violet was faint but visible on the screen; it has not registered in the photograph). There are more than seven colours in the spectrum, but there are still many colours, that are identified as basic by Berlin and Kay, that are not visible in the spectrum. There are no whites, blacks or greys, and no purples, browns, or pinks.

Purples can be added to the spectral sequence and the colours can be arranged in a circle as shown in figure 8B. There are no hard divisions separating colours in this circle. It can be subdivided into any number of separate colours. M.E. Chevreul, who produced this circle, produced another circle divided into 72 separate colours [7 pp.66-69].

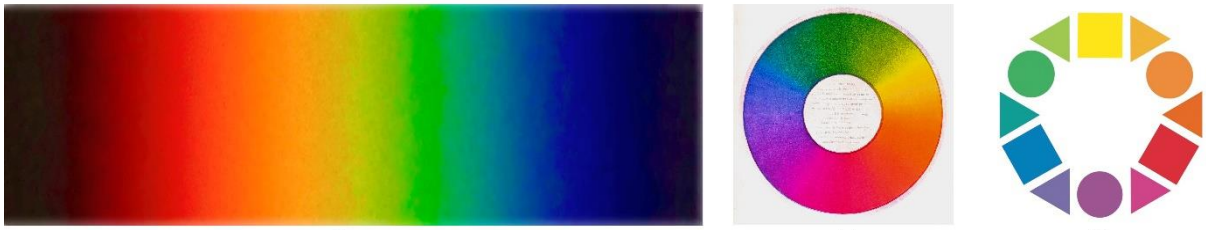


Figure 8: (A) Light from a projector refracted by a prism to form a spectrum; (B) Circular diagram produced by M.E. Chevreul with spectral colours, augmented by purple, in a blended sequence (Schindler 2009, 67); (C) Colour circle constructed from yellow, red, and blue 'primaries' (squares). 'Secondaries' are circles and 'intermediary' colours are triangles.

Early learning about the art of colour

In addition to books for pre-school children about colour terms and the rainbow, there are many other books that show illustrations of mixing paints using 'primary colours'. Even before starting school, some children are introduced to the colour circle or 'colour wheel', which is central to current accounts of 'colour theory'. These classroom colour wheels follow a long-established tradition with yellow, red, and blue as 'primaries' as shown in figure 8C. There is a place for purple in these colour wheels, but there is still no place for brown or pink.

The need in early education for a concept of the full range of colours

The uneven distribution of colour names, and the focus on vivid colours in two-dimensional models, presents a very incomplete picture of the colour universe. The traditional colour wheel is a cornerstone of colour theory, but it focuses attention on a small range of colours only. There is no place for the pale, dark and muted colours that children would have experienced when they were younger. As a prerequisite for learning about mixing paints and lights, and developing harmonious colour combinations, children must be able to imagine a more complete picture of the colour universe and be able to describe what they see.

A more complete picture is provided by the colour order systems such as Munsell, RAL, Ostwald, and the Natural Colour System (NCS). These systems have well over 1,000 colour samples, organised in three-dimensions, but are far beyond the basic needs of young children. Something much simpler is needed. A simple model can still convey a sense of the full range of colours.

A new sorting set for exploring colour relationships

Background

The research, described in section "Early learning about basic colour categories" above, led to a realisation and an idea. The realisation was that the uneven distribution of colour names in colour space is responsible for much of the confusion that students experience. The idea was to develop a system that goes beyond the colour wheel while remaining simple enough for young children to understand and use. This idea has a long history [6, 8].

There are systems available, with fewer colours, that are simpler than the comprehensive colour order systems, but most are still beyond the needs of young children. The New Munsell Student Color Set [9] is an abbreviated version of the Munsell system. It has ten hues and between 20 and 30 colours on each hue page. Two systems produced in Japan are based on the Munsell system: the Practical Colour Coordinate System [10] and the Hue and Tone System [11-12]. NCS Colour produce an excellent range of kits for colour education [13]. These systems and kits are all useful as introductions to colour ordering, but are more suited to students in the highest grades.

Design parameters for a new sorting set

Closest to what we had in mind is the sorting set produced in Germany by Andreas Schwarz [14]. The Schwarz set has ten hues, with four colours for each hue, as well as white, black and three greys. The colours are printed on stiff card. The set comes with printed sheets from which a simple three-dimensional model can be built to show how colours can be related.

Our design parameters were similar: an inexpensive, generic set with colours that can be carried easily in memory, and which can be organised in a three-dimensional framework. It must be possible to name each colour using everyday language. The colours should be printed on small tiles that are easy to pick up and move around.

In a previous study of the legibility of shapes and colours it was found that there are four factors that contribute to quick and easy recognition in a given context: simplicity, familiarity, contrast and nameability [15]. Our colours are organised in a simple three-dimensional framework, they are familiar, clearly differentiated, and easy to name. These considerations put a limit on the number of colours to be included, but at the same time the set of colours must be able to represent a broad range of the different colours that we can see. We looked for a middle ground between too many colours and too few.

A basic palette of colours

When choosing colours for the sorting set, we started with Hering's Yellow, Red, Blue, and Green, his 'urfarben', that are recognised as the unique hues [16]. We then added the in-between colours Orange, Purple, Turquoise, and Lime. If the latter colours are not already familiar, they are easy to imagine as colours that appear midway between unique hues.

With the four unique hues and four in-between colours we had a hue sequence of eight. However, when these eight colours were placed side by side it was clear that the visual steps from Red to Purple to Blue were much greater than those from Blue to Turquoise to Green. We decided to replace the single Purple with two colours: Magenta as a reddish purple and Violet as a bluish purple.

With nine hues there are added advantages. We avoid any direct link to established colour order systems and we avoid any direct connection to established principles of colour theory. The set of colours

is to be thought of as just that – a set of colours. It is not to be regarded as a guide to mixing or harmony. Ideally there should be no hierarchy; all colours should have equal status. At this first stage, no colours should be identified as 'primary' and no colour pairs should be identified as 'complementary'. These are matters that can be dealt with when children reach higher grades. At that time it will also be possible to add more hues to the sequence and more colours to each hue family.

The next step was to decide how many colour variations to include for each hue in the basic set. We referred to the colour triangle by Faber Birren [17 p.47]. This shows four variations, described by Birren as 'pure colours', 'tints', 'shades' and 'tones'. To avoid using terms that are more familiar to painters we describe the four variations as 'vivid colours', 'pale colours', 'dark colours', and 'muted colours'.

In addition to the 36 tiles, with nine hues and their four variations, we included nine other tiles that can be used to form a grey scale with white and black at the ends. This does mean that it is not easy to name individual greys, unlike the 'white', 'pale grey', 'mid grey', 'dark grey' and 'black' in the Schwarz set, but we find that a more extensive grey scale is useful in some sorting exercises.

This set of 45 colours was presented at AIC 2021 [18] and is shown in figure 9. Note that the colours are not specified precisely but are defined within a narrow range using the notations of the NCS and Munsell systems. Also listed for reference are reasonably close matches to the vivid colours from the standard set of *Crayola* crayons that are used in many pre-school and primary school classrooms in the USA and around the world.

HUE FAMILY	NCS RANGE	MUNSELL RANGE	CRAYOLA NAME
YELLOW	G90Y - Y	5Y - 7.5Y	YELLOW
ORANGE	Y40R - Y50R	2.5YR - 5YR	ORANGE
RED	Y90R - R10B	2.5R - 7.5R	RED
MAGENTA	R25B - R35B	1.25RP - 3.75RP	RED VIOLET
VIOLET	R55B - R65B	10PB - 2.5P	BLUE VIOLET
BLUE	R85B - R95B	10B - 3.75PB	BLUE
TURQUOISE	B30G - B50G	7.5BG - 10BG	BLUE GREEN
GREEN	G - G10Y	2.5G - 5G	GREEN
LIME	G40Y - G50Y	5GY - 7.5GY	YELLOW GREEN

Figure 9: The 45 colours of the basic set with the hue ranges in the Natural Colour System (NCS) and Munsell system. Also listed are reasonably close matches to the vivid colours from the set of 24 Crayola *crayons.*

No need for absolute precision

An important feature of this set is that the colour specifications are not precise. It is a fuzzy system that can tolerate slight variations of colour for a given position in the structure. This gives the system what we call the 'Post-It advantage' where expectations are overturned. One might expect that the value of a glue lies in how firmly it sticks, but a glue that does not stick very well can be extremely useful as

we have found with the invention of Post-It notes. A common assumption about colour order systems is that they should be as precise as possible, but here we argue for the value of a system that is somewhat imprecise and flexible.

The colours of the tiles in the sorting set do not have to meet high standards of precision; it is enough if the colours can be sorted into their hue families without any ambiguity about where any given colour should belong. We have found that the colours are sufficiently different from each other that any 'mistakes' in sorting are easy to recognise. (The same is true of the digital sorting set that is available online, described below. With the digital sorting set the differences between the colours need to be, and are, sufficiently robust that it is not necessary to have calibrated screens for the system to be usable.) As for lighting, the coloured tiles just need to be able to survive a variety of classroom conditions.

For the present we are focusing on people with 'normal' colour vision but we are certainly interested in the difficulties that might be faced by anyone with limited colour vision. We consider it very important that such students are not made to feel 'inferior' in any way. In the future we may be able to produce a sorting set with fewer colours but colours that can be discriminated by the great majority of students, including those with the most common forms of limited colour vision.

Terminology

Children need words to describe the colours they see. Since the sorting set is to be used in early education it is important that we use terms that can be understood by children as young as four.

The colour universe

This term for the full range of colours that can be perceived or imagined has been defined in the Introduction. It is a term for a concept that we believe children should have before the introduction of any other aspects of colour theory.

Hue family

For the dimension of hue we use the term 'hue family' rather than the single word 'hue' since young children, especially, are not familiar with that word. However, they can easily see the relationships between colours of the same hue and can readily associate that with the concept of 'family'. We combine the two words as 'hue family' to make the term 'hue' familiar for later use on its own.

Character

A second void in the language that we identified [1] is a term for describing sets of colours that share perceptual similarities unrelated to hue. There is no stand-alone word, commonly understood, that can be used to describe the sorting of colours into 'pale', 'dark' and 'muted' variations within each hue family.

Different systems order colours in different ways and most systems use two terms for two dimensions, in addition to hue, to locate colours in a three-dimensional space. A colour's position in Munsell space is determined by its 'value' and 'chroma'. In the NCS a colour's position is determined by its 'blackness' and its 'chromaticness', but the term 'nuance' is also used in the NCS for the combination of blackness and chromaticness that, together with its hue, locates a colour at a point within that system [19]. If nuance were more widely used it would fill this void in the language, but at present it is too closely associated with the NCS system where it is defined specifically in relation to the scales of

blackness and chromaticness. We need a general term that can refer to the position of colours in any system.

We have adopted the term 'character' and have found that young children can understand what is meant when they hear the term at the same time as they see colours that are all pale, dark, muted, or vivid. It is not difficult to think about different characters in the same family.

Lightness/value

The International Commission on Illumination (CIE) has published an extensive set of definitions in the *International Lighting Vocabulary* that is available online [20]. The term 'lightness' is defined as: "brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting." This is not a definition that is easy to understand, and certainly not for a four-year-old child. Young children can understand the idea of a 'light colour' as they can understand the idea of a 'pale colour'. We prefer the term 'pale' for colours that are seen to be between a vivid colour and white. 'Lightness', as defined by the CIE, relates a colour to a step on the grey scale and is equivalent to Munsell's term 'value'. To make that relationship clear we use both terms as alternatives for the same meaning. A colour's lightness/value is most easily established by finding the step on the grey scale where there is least contrast between the colour and the grey.

Grey partners

We have found the term 'grey partner' to be useful for identifying the step on the grey scale where there is the least contrast with the colour – where the lightness/value of the colour was established.

Chroma

The term 'chroma' is used in the Munsell system to indicate how vivid a colour appears. Although it was coined for use in the Munsell system it has entered the general language and is a useful term. Chroma would be a new word for young children, but we understand that children enjoy learning new words if the meanings are clear as in this case. Of the various definitions of chroma that have been published, Munsell's own is most helpful: "the degree of departure of a colour sensation from that of white or gray" [21 p.16].

Describing colours

Names for colours

With the terms 'hue family' and 'character' established it is possible to use those terms in a simple system for naming colours. For example, we can identify a colour as a 'vivid red' or a 'dark blue'. Reference to figure 9 will show how character and hue family connect. In the top row, after the white, are the members of the yellow hue family: 'pale yellow', 'vivid yellow', 'muted yellow' and 'dark yellow'.

The use of character and hue family to identify colours in this way can also help to resolve some of the confusion that may exist around the basic terms 'brown' and 'pink'. Many colours would be described as 'brown', but these colours are muted or dark – never vivid. 'Pinks' are usually pale, but not always. Reference to figure 7 will show that three-year-old Emily did describe some quite vivid colours as 'pink' but darker colours in the same range of hues were 'brown', 'red' or 'purple'. Neither 'brown' nor 'pink' can be the name of a hue family. In figure 9 the muted and dark members of the yellow and orange

hue families might well be described as 'brown' but they can also be seen to belong to the yellow or orange hue families. In a similar way, pale red and pale magenta might be described as 'pink' but they can also be seen to belong to the red or magenta hue families.

The range of hues that Emily and others would identify as 'blue' or 'green' is very extensive. People commonly argue over whether a turquoise is 'blue' or 'green', but turquoises can be seen to be quite distinct. They are bluish and greenish in the same way as oranges are yellowish and reddish. Limes are also distinct as being both greenish and yellowish. Figure 10 shows this system of names applied to a number of colour swatches.

Figure 10: Colour swatches identified by colour names that are a combination of character and hue family.

There are many opportunities for reinforcing an extended colour vocabulary like this. For example, children can learn to develop their powers of observation by 'collecting' colours rather like train spotters or bird watchers. After a visit to the shopping centre a young girl might announce that she had spotted some muted turquoise while her brother had seen some vivid orange. These sightings could be recorded and children could compete to see who would be first to record sightings of all the colours in the sorting set. This would certainly sharpen their awareness of colour and their sensitivity to distinctions of hue and character.

The value of an extended vocabulary

The way in which words like colour names can enhance our sensitivity to the environment has been described by Ammon Shea [22 p.208]. Shea undertook the eccentric project of reading all 20 volumes of the *Oxford English Dictionary*. He justifies his project like this: "I read the OED so that I might know what the words are for the things in the world that I had always thought to be unnamed. And perhaps if I know there is a word for something … I will stop and pay more attention to it."

Having words to describe what we see can certainly help us to perceive colours more clearly, but there is also a danger that the words themselves become more important than the actual experience of seeing the colours. Johann von Goethe [23 p.302] warns against this: "Yet, how difficult it is to avoid substituting the sign for the thing; how difficult to keep the essential quality still living before us and not to kill it with the word." Words may alert us to certain phenomena, as Shea points out, but finding the word should not be regarded as the main objective. What matters most is the visual experience of the colours themselves.

Testing the sorting set

For the Colour Literacy Project, we are working with groups of volunteer teachers and others who are helping us test our ideas in a series of workshops. They are giving us valuable feedback about how young children might respond to particular activities. Most of the teachers are non-specialists as far as colour is concerned and the ideas presented in the workshops have been new to them. As they have become more confident some of them have started to introduce the ideas in the classroom.

Some concern was expressed by the teachers that the children might be overwhelmed if they were faced with all 45 coloured tiles at the same time. Rather than introduce all 45 coloured tiles at once some teachers have used a small selection only. We saw how some very young children had been given a small selection of colours to sort from only a few hue families, and this they did with little difficulty. It is important that the teachers use the material as they judge it to be suitable for the age group in the class.

The number of tiles from the sorting set that are used for each exercise can be increased in stages as children get older and more confident. For example, at the pre-school age, the minimum number of tiles at the introductory level for the exercises could be four hue families, each with four characters, for a total of 16 tiles. This could be increased to six hue families at the next level and, at the final level, all tiles could be used – the nine hue families plus the nine tiles of the grey scale.

Arranging colours in order

Before beta-testing the sorting set with children, we have conducted a number of workshops with adults. One of the first exercises in the workshops has been to sort the colours into some kind of order without any instructions on what the basis for such an order should be. The basis for ordering should be discovered from simply looking at the colours. The instructions are: 'Arrange the colour tiles in order'. The basis for ordering is up to each person. Examples of such arrangements are shown in Figure 11.

Figure 11: Arrangement of colour tiles 'in order' by people testing the sorting set.

We have found that people make discoveries simply by looking at the colours. Often the first observation is that there is a fundamental difference between colours that are chromatic and those that are not. They may arrange the black, white and greys as a separate group altogether as seen in Figure 11.

When they arranged the chromatic colours, we found that most people grouped colours according to hue or according to what we are calling character. When the participants had completed their arrangements, we were able to point to the colour relationships that they had discovered for themselves.

The next tasks were to put the colours together in separate hue families and in separate groups of the same character. In a later session they were to arrange colours according to lightness/value and chroma.

Arranging colours in hue families

It is easiest to see how colours are related by hue if you simply look at the colours; it is more difficult to describe the meaning of the term 'hue' in words. Lisa Radomiljac is a former colleague of Green-

Armytage who is now teaching at a small school in the country south of Perth. Green-Armytage showed her a prototype set of tiles and, when he asked her how best to explain the concept of hue to young children, she said [24]: "Don't tell them, show them. Put together an arrangement of four tiles that have the same hue, explain that this is a 'family' and ask them to sort the remaining tiles into their separate families." This approach has worked very well. On the left of figure 12 the orange hue family has been arranged below the other colour tiles. The set of nine hue families is shown on the right.

Figure 12: Colours from the orange family separated from the others and arranged in a hue family group (left) and all tiles arranged in family groups (right).

Arranging colours by character

When the tiles have been organised into hue families, as shown in Figure 12, it is a simple matter to rearrange them into groups of the same character as shown in Figure 13.

Communication of meanings

Having a term like 'colour character' to fill the void in language is particularly desirable given that it is often this aspect of a colour's appearance, more than its hue, that communicates meanings. Books that introduce the ways that colours communicate meanings typically focus attention only on the hues and the vivid colours. The important role of character is clear from the work of Lars Sivik [25], who uses the NCS and his 'isosemantic maps' to plot colour connotations. This was also a key finding from the research of Valdez and Mehrabian [26] and Ellen Divers [27].

When our volunteer teachers had organised the colour tiles into groups according to character, we asked them to write words for the meanings they derived from the groupings (figure 13). The words they wrote provided further evidence that meanings are associated not just with a colour's hue but especially with this other aspect of a colour's appearance – its character.

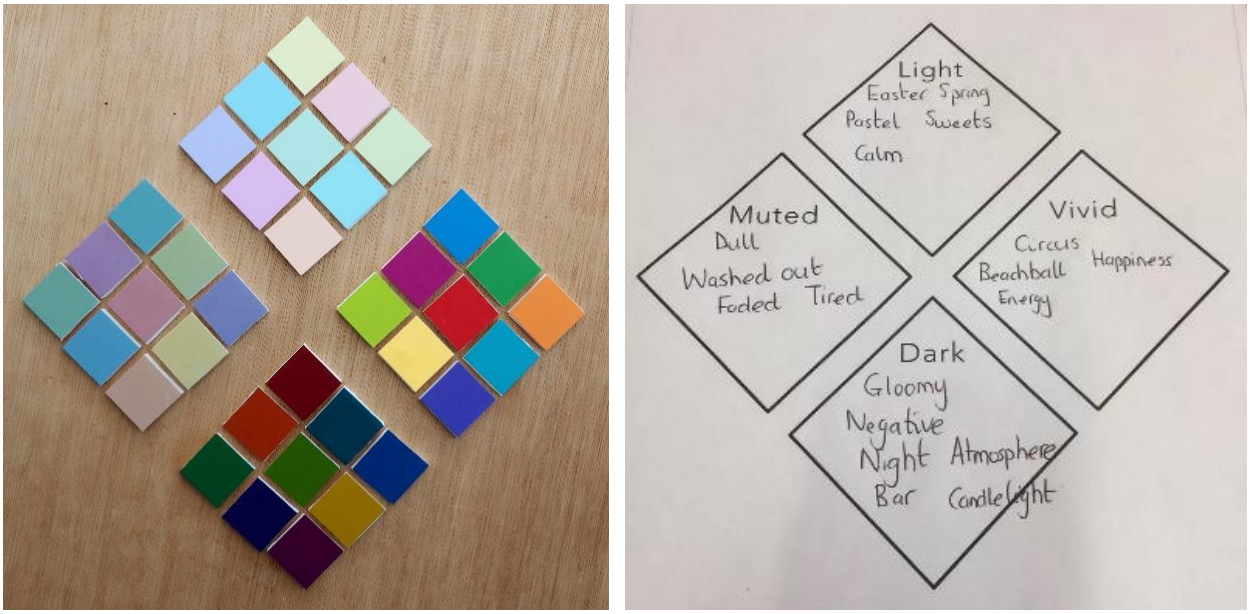


Figure 13: Colours organised by character and some words for the meanings suggested by the colours.

Arranging colours according to lightness/value

The first step here was to construct the grey scale from white to black. The task was then to find the grey partners of the colours from the yellow and violet hue families. With only nine steps in the grey scale, it was found that a colour's position in relation to the scale was often between two steps on the scale. While some found the task difficult the instruction itself was very simple and people just had to use their eyes as they made their judgements (Figure 14).

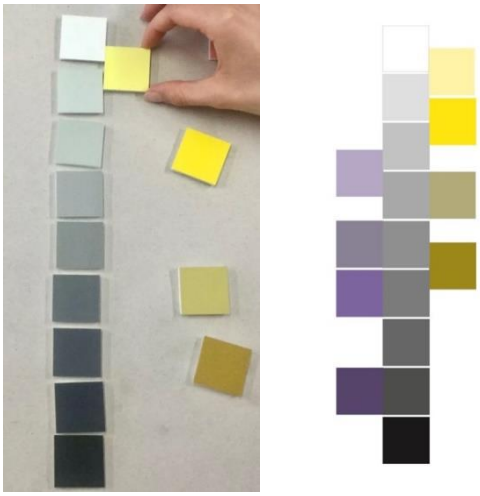


Figure 14: Arranging colours from the violet and yellow hue families next to their 'grey partners' on the grey scale.

Arranging colours according to chroma

Having made their judgments of lightness/value in this way the next task was to judge how vivid each colour was. Here we introduced the term 'chroma'. This is another task that depends on visual judgement. We used Munsell's definition of chroma as the 'degree of departure of a colour sensation from that of white or gray'. There was no scale to use as a guide, as there is for judging lightness/value,

but people could make judgements when they had colours from different hue families that clearly had different degrees of chroma (Figure 15).

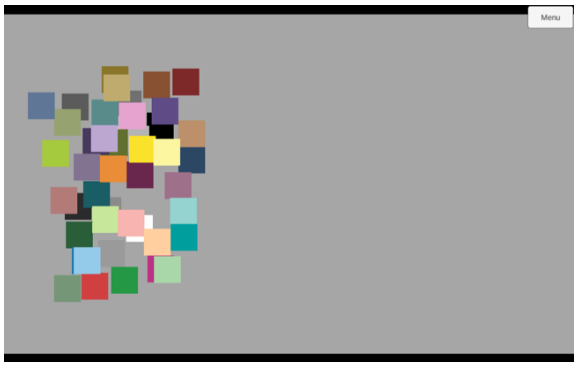
Figure 15: Arranging colours opposite their 'grey partners' and at distances from the grey scale to indicate their chroma (vividness).

An online sorting set

A prototype digital version of the sorting set has been created for the Colour Literacy Project by Joey Sipos [28] and is available online. Additional features may be added, and we are working on a set of instructions to be provided as part of the package. The menu offers three shapes: a diamond, a square and a circle. There are three levels. The introductory level has four hue families – vivid, pale, dark, and muted colours for each of four hues – plus black, white and mid grey. Level 1 has six hue families and, at level 2, all nine hue families are displayed for sorting. The nine tiles of the grey scale can be added at any time. The tiles of level 2 can also be added in groups – vivid, pale, muted, dark, and neutral (white, black and greys) or added as all colours together.

Arranging colours according to chroma

Figures 16 to 23 are screen shots taken to illustrate the use of the online sorting set.



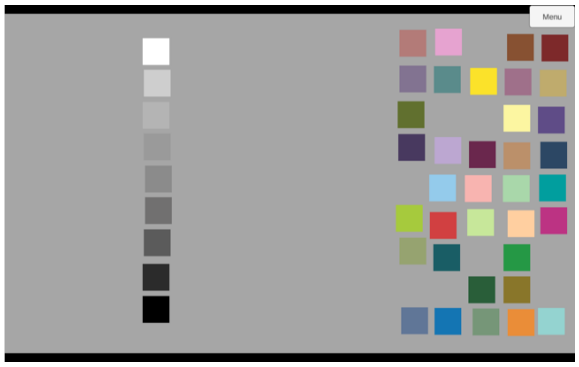


Figure 16: (left) All colours added in random order.
Figure 17: (right) After moving the colours to the right, nine colours have been moved to form the grey scale.

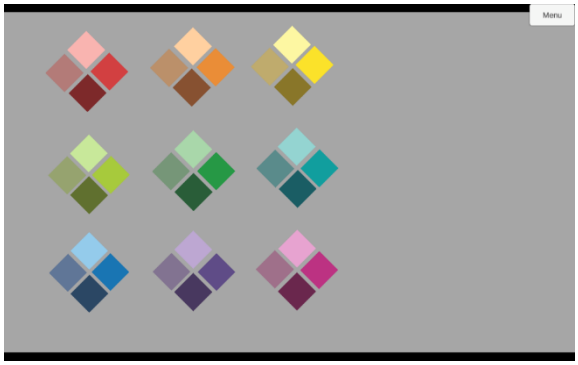
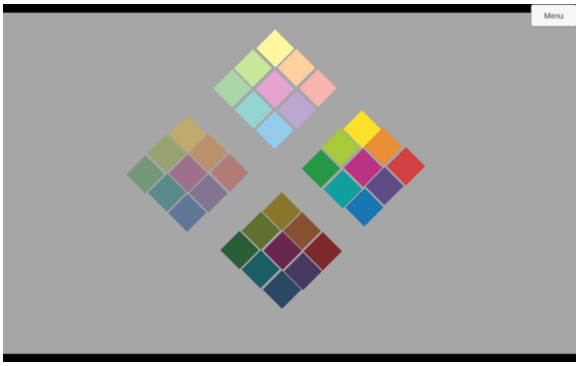



Figure 18: (left) Colours arranged in hue families.
Figure 19: (right) Colours arranged in groups of the same character.

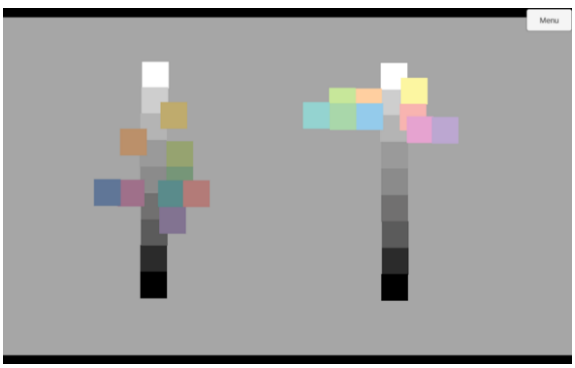
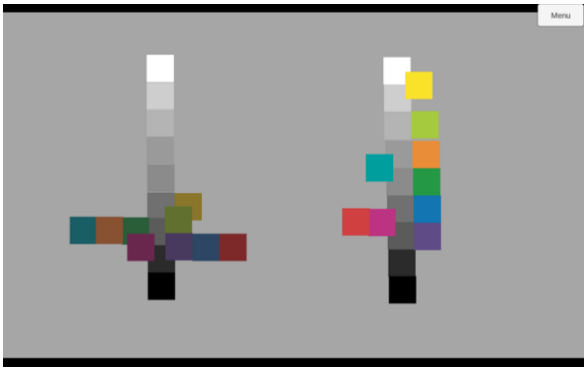



Figure 20: Muted and pale colours connected to their grey partners to show their lightness/value.
Figure 21: Dark and vivid colours connected to their grey partners to show their lightness/value.

Introduction of the hue sequence

During the workshops with the volunteer teachers, we also introduced the hue sequence with colour tiles arranged in a circle. A circular hue sequence can also be arranged with the digital sorting set (Figure 22).

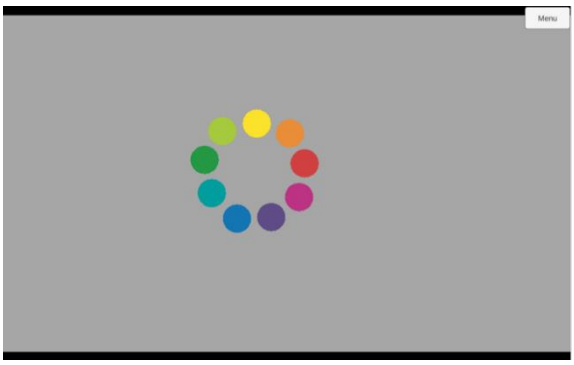
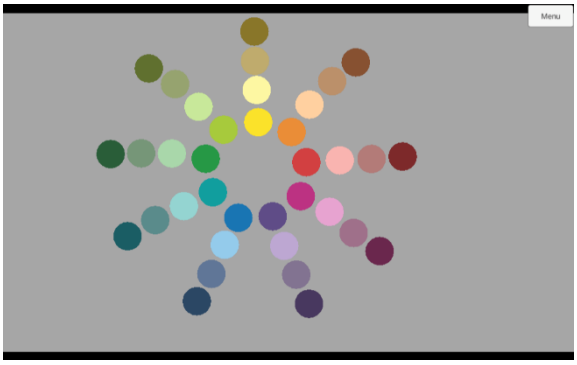



Figure 22: Colours arranged in a circle to show the hue sequence.
Figure 23: Pale, muted, and dark colours added outside the vivid colours so that colours from the same hue families are on radiating lines.

Introduction to colours in three dimensions

The next step is to show how the colours in the set are related in three dimensions. Colour order systems are three-dimensional models and typically have more than 1,000 colours. Our set of colours constitutes a very basic colour order system with a limited but representative set of colours. The number

of hue families used to build the model can be varied and increased in stages based on the number of tiles used in the sorting set at a given stage. The model described below is based on the level 2 sorting set.

Structure of the model

The nine vivid colours can now be arranged in a circle. This will follow the spectral sequence from Red to Violet with Magenta, as the connector, to complete the circle. This is a nine-step hue circle. The sequence of hues can follow a clockwise or counterclockwise direction. The choice of direction is essentially arbitrary, as is the choice of which colour should be placed at the top of the circle. We have chosen to follow the majority where yellow is at the top and the sequence from yellow to orange etc is clockwise (Figure 24).

Figure 24: Nine step hue circle with mid grey in the middle.

Mid grey is shown here at the centre of the circle. The paler greys and white would be located above and the darker greys and black below. White, black, and the vivid colours are at the points of Birren's triangle which can now accommodate the colours of each of the nine hue families (Figure 25).

Figure 25: Faber Birren's colour triangle (outline on the left) with the colours of the yellow hue family in position on the right.

Figure 26 shows the colours of the yellow hue family in the form of what we call a 'hue plane' beside a five-step grey scale. Maggio has developed a model to show how hue planes for the nine hue families can be arranged to show how the colours of the sorting set relate in a three-dimensional space. The discs to which the hue planes are connected represent the central grey scale axis (Figure 27).

Figure 26: The yellow hue family as a hue plane next to the grey scale.
Figure 27: Model showing how hue planes for the nine hue families relate in three-dimensions.

Different structures for colour order systems

In an invited lecture at the Forsius Symposium on Colour Order Systems W.D. Wright [29 pp.36-46] identified two broad groups of colour order systems that are structured with different variables. An example of one group is the Natural Colour System (NCS) with its scales of hue, whiteness, blackness and chromaticness. (Chromaticness is roughly equivalent to vividness). Maggio's model shown in figure 27 belongs in this group.

An example of the second group identified by Wright is the Munsell system with its variables of hue, value and chroma. Munsell 'value' is the equivalent of lightness/value as defined above. 'Chroma' is also defined above and is broadly similar to NCS chromaticness as another term for vividness. Where the NCS has all the most vivid colours arranged at the same level as mid grey, in the Munsell system the colours are placed at their own levels of lightness/value. Figure 28 shows colour tiles from the yellow hue family placed on hue planes from the NCS atlas and the Munsell Student Color Set.

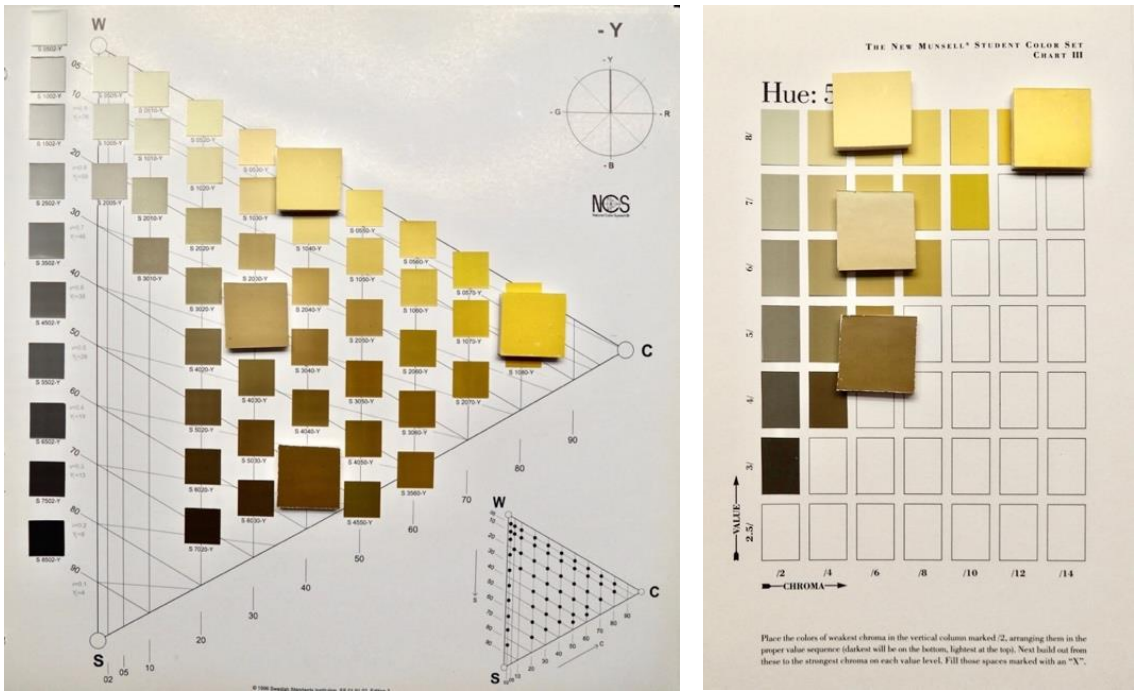


Figure 28: Tiles from the yellow hue family placed on pages from the NCS atlas (left) and the Munsell Student Color Set (right).

An elastic colour solid

The two structures identified by Wright each have their advantages, and neither is 'better' than the other. Our concept of the colour universe is that it is malleable or elastic. It would be possible for colours that are organised according to one structure to 'morph' from their positions in that structure to those in another. This possibility can be seen by referring to Figure 28. The most dramatic shift would be for the vivid yellow to move from the same level as mid grey up to the level of a pale grey.

Maggio has developed new models, with additional characters on the hue planes, to show how it is possible to morph from one structure to another. Figure 29 shows two variations of hue planes for violet and yellow in relation to the grey scale. On the left the colours are positioned so that the vivid colours are at the same level of lightness/value as mid grey. On the right the hue planes have been adjusted so that vivid yellow and vivid violet are opposite their grey partners. The vivid yellow has also been moved further from the grey scale to reflect the judgement that it has higher chroma than the vivid violet. The other colours in their hue planes would be adjusted accordingly.

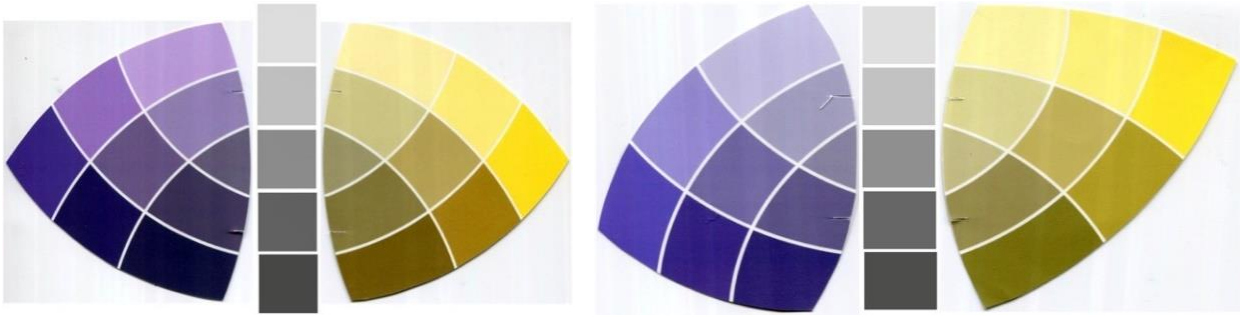


Figure 29: Two variations of the hue planes for violet and yellow with additional characters. These illustrate the possibility of one structure of the colour solid morphing into that of another.

The colour circle can also be elastic. Although we are not concerned with notions of primary colours or complementary colours at this stage, we can point out that different ways of defining complementary colours have shown that different definitions do not yield the same colour pairs. If the different definitions are to be accommodated, so that 'complementary' colours are opposite to each other, the hue circle also needs to be elastic. It must be possible to increase the distance between some hues and decrease the distance between others. The advantages of an elastic colour solid have been described by Green-Armytage [30]. Maggio has produced a fan-deck which enables the user to display the four introductory hue families, the six level 1 hue families, and the nine level 2 hue families. It is also possible to adjust the spacing between each (Figure 30).

Figure 30: Fan-deck produced by Maggie Maggio for displaying hue families in sequence. The number of families can be altered and the spaces between families can be adjusted.

Connecting colours to objects

The physical sorting set tiles can be used to help students recognise and describe the variations of colours in objects.

One of the tasks that was included in the workshops with our volunteer teachers was to collect objects with colours from closely similar hue families and then to select the objects where the colour was closest to the pale, dark, muted, and vivid tiles (Figure 31).

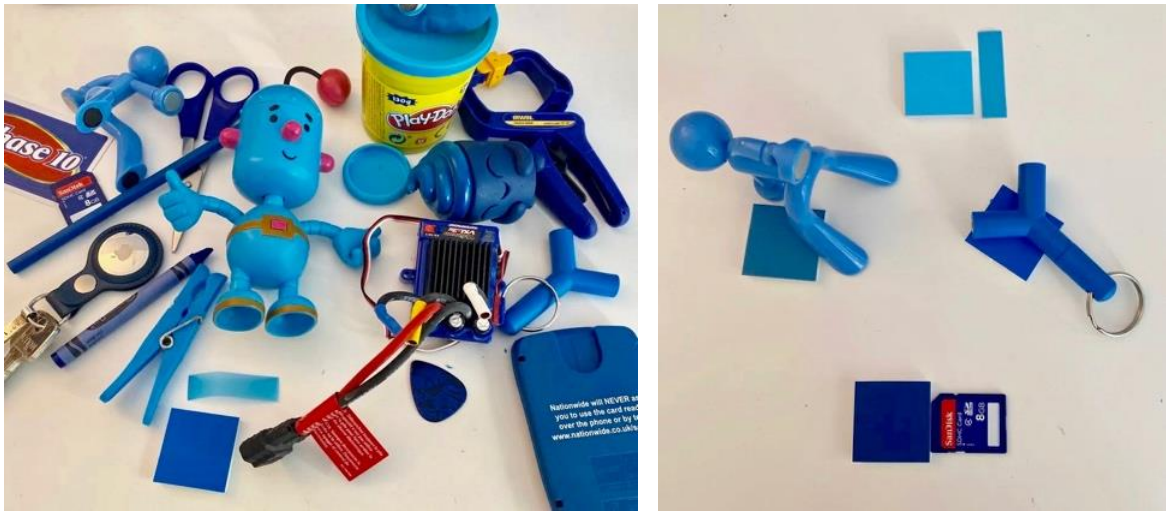


Figure 31: Collection of blue objects from which four were selected that were best examples for pale, dark, muted, and vivid colours.

A possible exercise for the future is illustrated in Figures 32 and 33. This shows screen shots of two slides from a PowerPoint file. Above the set of colours from the sorting set are seven photographs of objects with a dominant colour. The task is to drag the photographs into position over the grid of colours. Note that some of the objects have colours that fall between two hue families or characters. This makes the point that the colours of the sorting set are simply convenient landmarks in colour space.

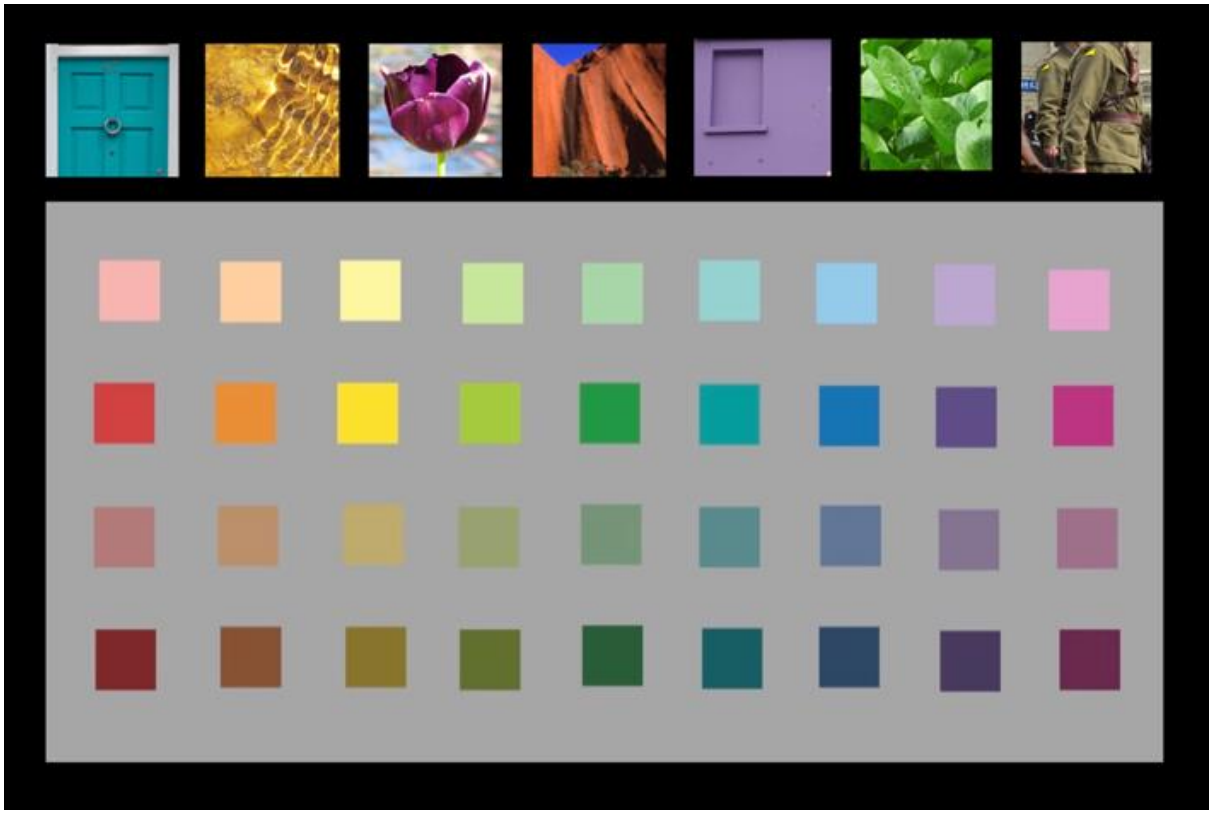


Figure 32: Colours of the sorting set below seven photographs with a dominant colour.

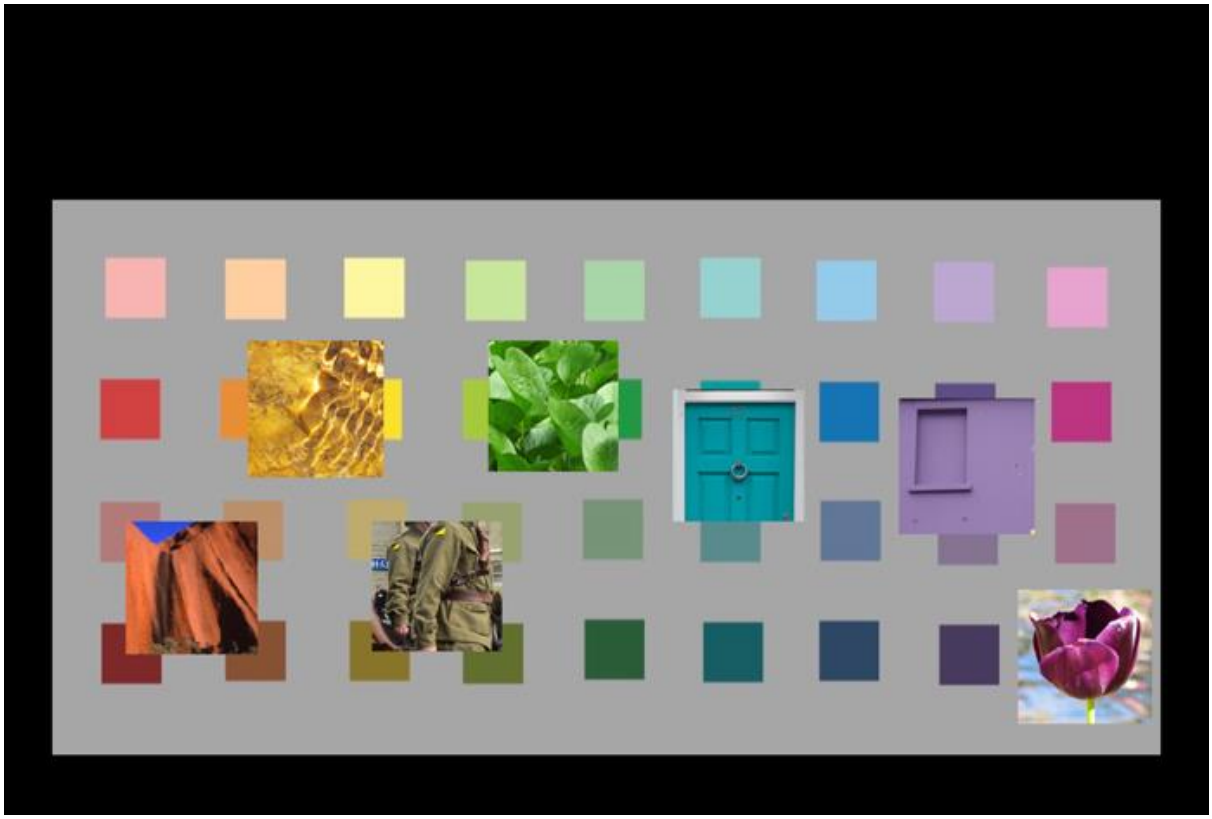


Figure 33: Photographs from the top moved into position over the grid of colours.

Conclusion

The emphasis of all the ideas presented here is on attentive looking, exploration, and discovery. The key concept is the colour universe and the aim is to help students grasp this concept so that they can understand how one colour can be paler than another, darker, more muted, or more vivid. While systems for organising colours in three dimensions could be regarded as 'colour theory' the key purpose here is simply to provide a frame of reference that will help children to discriminate and describe colours. The colour tiles of the sorting set are designed to help students appreciate the differences and relationships between colours and to understand how they are related in three-dimensional space. This conceptual model can then be a point of reference for identifying all the colours, in their rich variety, that students perceive in their surroundings.

We are in the process of collecting real data to support the claim that having this conceptual framework has enhanced people's sensitivity to the colours in their environment. We already have one encouraging comment. One of our participants acknowledged that she had not really looked at the world in this way before and that she had become much more aware of colours in all their variety.

In our 'Before Colour Theory' workshops we have not identified any colours as 'primary' and have not introduced methods of mixing paints or lights to produce other colours. Whatever processes are used to produce other colours from mixing, the important thing is to be able to observe the results and to determine whether the desired colours have been produced. We need to be able to judge for ourselves whether the theory that 'red and blue make purple' is supported by our own experience, especially when a mixed 'purple' is far from the vivid colour we had in mind.

Theories about what kinds of colour relationships are harmonious also need to be supported by our own judgements. We prefer an approach to harmony that is based in observation. Instead of starting with notions of complementary colours, analogous colours, and triads, and teaching students that such colour combinations are harmonious, we prefer to start from the other direction. Students can look at colour combinations in nature, in art, and in the built environment and can record the colours they observe. If we start with a few such colour combinations, and find that there is consensus about which combinations are the most pleasing, then we can take note of how the colours are related. We have a concept of the colour universe and have a language for recording what we discover.

We believe that a well-developed ability to discriminate colours, having the language to describe the appearance of colours, and the understanding of how colours are related to each other in three-dimensional space, are important basic skills for everyone. In education they are prerequisites that will enhance learning and enable students to look and think critically when they come to apply other aspects of 'colour theory'.

Acknowledgements

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References

1. Maggio M, Green-Armytage P and Divers E (2022), Two voids in the language of colour, *Proceedings of the Midterm Meeting of the International Colour Association: AIC 2022 Sensing Colour*, 241-247, Toronto, Canada.
2. Albers J (2013), *Interaction of Color*, New Haven: Yale University Press.
3. Riley B (1999), *The Eye's Mind*, London: Thames & Hudson.
4. Vanstone E (2013), How to make giant bubbles, *Science Sparks*. [https://www.science-sparks.com/making-giant-bubbles/ – last accessed 1 October 2022]
5. Berlin B and Kay P (1991/1969), *Basic Color Terms*, Berkeley and Los Angeles: University of California Press.
6. Green-Armytage P (1980), Violets aren't blue: Colour sensations and colour names, *Arts in Cultural Diversity*, Condous J, Howlett J and Skull J (eds.), 166-175, Sydney: Holt, Reinhart, and Winston.
7. Schindler VM (2009), Michel Eugène Chevreul, *Farb-Systeme 1611-2007: Farb-Dokumente in der Sammlung Werner Spillmann*. Spillmann W (ed.), Basel: Schwabe Verlag. [Illustration of Chevreul's colour circle reproduced with permission.]
8. Green-Armytage P (2002), Colour zones – Explanatory diagrams, colour names, and modifying adjectives, *Proceedings of the 9th Congress of the International Colour Association*, 861-864, Rochester NY, USA.
9. Capital Cities Media (1994), *The New Munsell Student Color Set*, New York: Fairchild Publications.
10. Japan Colour Research Institute (1991), *PCCS Harmonic Color Charts 201-L*, Tokyo: Japan Color Enterprise Co. Ltd.
11. Kobayashi S (1981), The aim and method of the color image scale, *Color Research and Application*, **6** (2), 193-107.

12. Kobayashi S (1987), *A Book of Colors*, Tokyo: Kodansha International.
13. NCS Colour (2023), *Educational Material*. [https://ncscolour.com/product-category/shop/educational-material/ – last accessed 6 March 2023].
14. Schwarz A (2014), *Kleines Farbenpraktikum*. [Available with Wege zur Kunst – Begriffe und Methoden für den Umgang mit Farbe. Braunschweig: Schroedel.]
15. Green-Armytage P (2010), A colour alphabet and the limits of colour coding, *Colour: Design & Creativity*, **5**, Ar. 10, 1-23.
16. Hering E (1964/1920), *Outlines of a Theory of the Light Sense*, Cambridge, Massachusetts: Harvard University Press.
17. Birren F (1969), *Principles of Color*, New York: Van Nostrand Reinhold Company.
18. Green-Armytage P and Maggio M (2021), Beyond the rainbow: a new sorting set for teaching colour, *Proceedings of the 14th Congress of the International Colour Association: AIC 2021*, 1097-1102, Milan, Italy.
19. Hård A and Sivik L (1981), NCS - Natural Color System: A Swedish standard for color notation, *Color Research and Application*, **6** (3), 129-138.
20. Commission Internationale de L'Eclairage (2020), *CIE S 017:2020 ILV: International Lighting Vocabulary*, 2nd edition. [https://cie.co.at/publications/ilv-international-lighting-vocabulary-2nd-edition-0 – last accessed 2 October 2022].
21. Munsell A (1946/1905), *A Color Notation*, 17th Edition, Newburgh, New York: Munsell Color Company.
22. Shea A (2008), *Reading the OED*, New York: Perigree.
23. Goethe J (1970/1840), *Theory of Colours*, Cambridge, MA: The M.I.T. Press.
24. Radomiljac L (2019), *Private Conversation on 3 August 2019*.
25. Sivik L (1977), The language of colour: Colour connotations, *Colour for Architecture*, Porter T and Mikellides B (eds.), London: Studio Vista.
26. Valdez P and Mehrabian A (1994), Effects of color on emotions, *Journal of Experimental Psychology: General*, **123** (4), 394-409.
27. Divers E (2020), Beyond hue: The affective response to value and chroma, *Proceedings of the Second Russian Congress on Color: RUcolor2020*, 154-159, Smolensk: Smolensk State University Press.
28. Sipos J (2023), Chromo colour sorting set, *Colour Literacy Project*. [https://5drealities.itch.io/colour-lit-sorting – last accessed 9 March 2023]
29. Wright WD (1983), The basic concepts and attributes of colour order systems, *Colour Report F 28. The Forsius Symposium on Colour Order Systems and Environmental Colour Design*, Hård A and Sivik L (eds.), Stockholm: Scandinavian Colour Institute.
30. Green-Armytage P (2018), Relating Munsell to other systems in an elastic colour solid, *Color Research and Application*, **43** (6). 815-826.