The Colour Literacy Project: Revitalising colour education foundations

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An overview of the Colour Literacy Project's revitalised colour curricula for elementary through to high school levels is presented. The Colour Literacy Project is working on identifying the basic concepts that are fundamental to learning about colour across all disciplines, in order to develop a foundational curriculum for colour for all students, not just art and design students. We recognise that a multi- and interdisciplinary approach is key for making colour education relevant for the 21st century. Colour is an ideal STEAM (Science, Technology, Engineering, Arts and Math) subject, and also crosses into many other subject areas including social and cultural studies. Our approach is to 'teach the teachers'. We have designed experiential and inquiry-based prototype exercises and resources for teachers that merge the current science and art standards related to colour. We aim to replace the common misconceptions and misinformation about colour with up to date, peer-reviewed information. Our two foundational series, the 'Eye-opener' and the 'STEAM' series, each contain a set of introductory exercises that begin with seeing and describing colour with all its attributes, a glossary that builds a unified vocabulary about colour from basic to advanced terminology, and explicit learning outcomes. We have begun beta-testing our prototype exercises aimed at revitalising colour education foundations. This paper discusses our approach and preliminary results of our teacher training sessions from elementary through to high school levels.

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Introduction

Colour surrounds us. It is a visual language that affects how we feel and how we interact with the world around us. It helps us communicate, and engage with our surroundings. Although colour is ubiquitous, and plays a critical role in the way we understand and shape our world, the topic of colour plays a limited role in elementary, middle and high school curricula, and is primarily confined to the art classroom. This is unfortunate because colour is an enticing topic and has great potential to inspire meaningful engagement with many aspects across the curriculum. Colour also permeates our digital lives. With the daily inundation of colourful images, videos and advertisements, digital technology has exploded and become an integral element of our culture. *Colour literacy* is now paramount to navigate in a world in which colour is so accessible.

Colour literacy fuses *Science* literacy with *Visual* literacy. Science literacy is "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. … a person has the ability to describe, explain, and predict natural phenomena." [1]. Visual literacy is "… the ability to interpret, comprehend, appreciate, use, and create visual media, in ways that advance thinking, decision-making, communicating, and learning." [2]. By using colour as a launching point to simultaneously delve into science and art, and even further into other subject areas, students' communication and critical thinking skills can develop in multiplicative ways.

The *Colour Literacy Project* is a joint educational initiative of the Inter-Society Colour Council (ISCC) and the International Colour Association (AIC/Association Internationale de la Couleur). The primary objective for the Colour Literacy Project is to develop foundational study material for teachers of all educational levels, as well as the general public, with a "top-down/bottom-up" approach, simultaneously addressing colour education upwards from preschool, and downwards from post-secondary levels. We have identified common misconceptions and misinformation about colour which are present in current curricula, and are replacing those with up to date, peer-reviewed information in our teacher resources. We recognise the need for a multi- and interdisciplinary, overarching framework that connects colour with all sorts of curricula – science, history, math, geography, language, dance. Colour is not just for artists. In this paper we discuss the development of prototype exercises for a revitalised approach to teaching colour foundations from elementary through to high school levels.

"The most significant pedagogical developments in twenty-first century learning may not be just the continued specialisation of skills and knowledge, but the pedagogical developments through which educators and educational institutions organise learning and teaching in ways that fuse arts, sciences, mathematics and humanities domains through contemporary real-world curricula that enhances learning potentials, creative possibilities and adaptive growth-mindsets in learners." [3].

Background

The seeds for the Colour Literacy Project began at the ISCC/AIC Munsell Centennial Color Symposium held in Boston, in 2018. Here, many colour educators and practitioners voiced their concerns over the current state of colour education. Briggs identified several flawed explanations common within the framework of colour education in art and design, as well as many misunderstood scientific explanations relating to colour perception [4]. Hirschler et al. also identified misconceptions, including erroneous notions of colour mixing processes, and made recommendations for the inclusion of scientific topics in the education of non-science students, such as spectral reflectance curves, metamerism and the CIE system [5]. Prior to the Munsell Symposium, Schwarz completed a 5-year qualitative-empirical study on the impact of misconceptions present in colour teaching on both art teachers and students in Germany [6]. As a response to these issues and concerns about the state of colour education, the Colour Literacy Project formed as a joint initiative between the ISCC and AIC in order to define best practices for teaching about colour and colour phenomena to *all* students (not only art and design students), with the goal of making colour education relevant for the 21st century. The tenets for the Colour Literacy Project are given on our website [7] and describe our understanding of the fundamental facts about colour.

The Colour Literacy Project Team consists of international colour experts and practitioners from diverse disciplinary backgrounds, who are concerned that colour is playing an ever-diminishing role in

art and design education worldwide, and plays an even lesser role in other subject areas. Most colour education today still revolves around curricula developed in the 1960s or earlier, which has been over-simplified, removed from its context and transformed into a reductive (and somewhat stale) theoretical framework of knowledge. It has unfortunately been reduced to snippets of colour 'facts'. What has been lost is a colour education which fosters a desire to investigate and explore colour, in all its complexity and nuance (and messiness). This over-simplification of colour knowledge has also contributed to many misconceptions about colour, which are widespread amongst artists and designers, as well as the general public. What is very often taught and published today as "foundational colour knowledge" generally rests on two topics: 1) How red, blue and yellow- coloured paints mix; and 2) The misconception that there are only seven colours in the spectrum or rainbow. Colour is so much more.

Background research

Surveys of colour educators

In 2019 and 2020, surveys were sent to colour educators to document current content, approaches, and methodologies in colour education. Surveys were sent to members of the AIC Study Group on Colour Education; non-profit educators in Portland, Oregon; elementary teachers participating at the Art of Ed Winter Conference in 2019; and secondary and post-secondary art and science teachers, primarily in Canada.

From the survey of 134 participants, we found:

1. Most colour education in art and design still relies on using the historical Red-Yellow-Blue (RYB) colour wheel as the principal means of organising colour. In our survey of 105 elementary teachers, 76% use RYB as their main colour wheel, and in our survey of 29 secondary and post-secondary teachers, 48% use RYB, 44% use Cyan-Magenta-Yellow (CMY), and 29% use RGB systems.
2. A distinct lack of teaching 3-dimensional systems of colour, with an over-reliance on simplified 2-dimensional systems (i.e. colour wheels). In our surveys, 90% of elementary and 45% of secondary and post-secondary teachers do not teach 3D colour spaces.
3. Little if any coverage of printing or computer colour. Coloured digital media feature widely in today's world, and should be an integral component of colour education in the 21st century.
4. Definite interest in collaborative, interdisciplinary approaches in teaching colour. Only 10% of elementary school teachers had experience with interdisciplinary collaborations but 70% expressed interest in interdisciplinary collaborations in the future. Secondary and post-secondary educators had more experience in interdisciplinary collaborations in the classroom (35.7%) with an additional 32.1% interested in collaborating.

Common misconceptions about colour

We have identified many common misconceptions about colour and a number of gaps in general colour knowledge. These were identified based on a review of easily accessible colour educational materials for the general public (including websites, videos, blogs), results from breakout discussions at the 2020 AIC Study Group on Colour Education annual meeting, and the teaching experiences of the Colour Literacy Project members. The misconceptions and knowledge gaps include:

1. Ignorance of the perceptual and relative natures of colour.
2. Lack of awareness that colour research is ongoing and knowledge is constantly changing and evolving. This is particularly problematic in art and design disciplines, where the standard model of teaching colour has ossified.

3. Widespread misinformation about colour on websites and social media: difficulty in determining the reliability of sources; difficulty in identifying the difference between personal opinions vs. facts supported by scientific research.
4. Not acknowledging the role and importance of colour and light in our built and natural environments.
5. Lack of awareness of the fundamental interdisciplinary nature of colour, and its potential use to bridge across disciplines.

Further specific misconceptions about colour have been discussed in Hirschler et al., who describe how the teachings of Traditional Colour Theory have been oversimplified and often misinterpreted [8]. They discuss misconceptions about colour related to primary colours, colour wheels, overly simple rules for harmonious colour combinations and the difficulty in attaching colour meanings to simple hues. Vazirian *et al*. discuss four misconceptions related to colour and light [9].

Objectives of revitalised colour curricula

With the results of the survey for colour educators, and concern for widespread misconceptions about colour, the Colour Literacy Project developed the following objectives for revitalising colour curricula:

1. Identify the basic concepts that are foundational to learning about colour across all disciplines: start with observing phenomena and build a strong foundation using experiential and inquiry-based learning.
2. Design exercises and resources for teachers that merge the current science and art standards related to colour. Exercises will be scaffolded, with a glossary that builds a unified vocabulary about colour from basic to advanced terminology, and contain explicit learning outcomes.
3. Replace the common misconceptions and misinformation about colour with up to date, peer-reviewed information.

Colour curriculum development

Our approach: Teaching the teachers

The Colour Literacy Project has targeted 'teaching the teachers' as the best way to introduce new ideas about colour teaching. The material provided is foundational and appropriate for all levels of teaching; a specific teacher can then modify the material for their particular classroom setting. We employ the approach of the Biological Sciences Curriculum Study (BSCS) 5E Instructional Model: Engagement, Exploration, Explanation, Elaboration, and Evaluation [10]. We also follow the recommendations of Allina for best practices in high quality STEAM (Science, Technology, Engineering, Art and Mathematics) Education [11]. Materials align with the U.S. Next Generation Science Standards [12] and the U.S. National Core Arts Standards [13].

Over the last three years, we have developed new colour curricula that begins with looking, seeing and experiencing nuanced variations of colour, rather than starting with the standard mixing of red-yellow-and-blue coloured paints, and merely using the colours of the rainbow 'ROYGBIV' to introduce colour. The bulk of colour curricula today resides in art programs, and in many cases relies on teachings derived from Johannes Itten's Art of Colour [14]. His 7 types of colour contrast are found as yearly learning objectives in the Ontario Ministry of Education's Ontario Visual Arts Curriculum Grades 1-8 [15]. This distillation of his teachings has unfortunately evolved into an overly-prescriptive means of teaching about colour. See a critical review of Itten's seven contrasts in this issue by Hirschler and

Schwarz [16]. In science curricula, colour plays a minor role in sections on light and colour. In the entire Ontario high school science curriculum, only Grade 10 Science overall expectations for Physics: Light and Applications of Optics contain specific references to colour [17]. A similar approach to teaching colour is found in other jurisdictions.

To test our revised curriculum, we have run (or are currently running) teacher training sessions with St. Teresa's RC School in Salford, England, Morristown Beard School in New Jersey, and Da Vinci Middle School in Portland, Oregon. Introductory training sessions were held with teachers at Clinton Public School in Toronto, Ontario, Canada. Each online training module runs for 3-6 sessions, at 1-2 hours per session. We have developed Teacher Guides, which contain exercises, learning outcomes, guided questions, 'more to explore' exercises for enhanced learning, and a foundational colour vocabulary. For our current training sessions, we provide materials to the schools for the exercises. We acknowledge that the teaching materials need to be easily accessible and inexpensive. In the long term, the Teacher Guides will be posted on our website[1]. Preliminary results of our teacher training are discussed following the next section.

Why we ditched the colour wheel

One of the most common starting points for the study of colour, which we are distinctly avoiding, is the construction of a painted 'colour wheel' or 'hue circle'. Instead, our starting point for exploring and expanding the way we experience colour in our world begins with looking, seeing and describing colour in all its variations: vivid, muted, pale and dark.

Colour is complex, and our relationship to colour is filtered by our culture, our experiences and our memories. By reducing our means of dealing with colour to a two-dimensional circle of the most vivid hues, we are missing out on all the nuanced variations which inform how we see and communicate with our world. Instead, we recognise that being able to describe colour with all its attributes – like hue, lightness and chroma – at an early stage of studying colour, ultimately gives a firmer grasp on understanding our visual world.

A colour wheel with its associated colour 'relationships' both restricts and redacts what colour actually is. When we start to study colour by learning the terminology of Traditional Colour Theory – like primary, secondary, tertiary, complement – colour becomes housed within a conceptual framework. This restricted way of looking at colour is problematic, as it can potentially limit how people actually see and experience colour. In our approach, experiencing colour is first and foremost.

One of the many problems with the traditional colour wheel is that there are so many variations. Which one is the 'best' or 'correct' version? The heart of the problem with the traditional colour wheel is that using only three so-called 'primary' paint colours to mix all others is actually a misconception. The physicality of the paint-mixing process means that it is impossible to produce 'all' colours from a limited set of three. Each set of three – whether comprised of red, yellow and blue-, or cyan, magenta and yellow- coloured paints, will result in a different set of mixed paint colours (and none contains 'all' perceivable colours). Each choice of a specific paint colour, whether it is a cadmium red light or a naphthol red, will result in a different set of mixed colours. Even the chosen brand of paint will impact the set of mixed colours. This multiplicity of colour wheels is a common point of confusion for introductory and even advanced students of colour.

Understanding that there is no 'true' or 'correct' colour wheel requires a deep understanding of the way colour and colourants work. Colours are what we perceive when we receive light into our eye: our

[1] www.colourliteracy.org

human visual system constructs the particular colour we see, taking the overall context into account. This is an extremely complex process. By working with a painted colour wheel, the focus is on colourants, and the way they behave and interact with light and with each other. Colourants, or coloured media, are not the same as perceived colours. Using the colour wheel with all its 'relationships' as the guiding principle for introducing how colour works and what colour is, is overly restrictive.

The Colour Literacy Project presents a new way to teach colour. Rather than starting with the ubiquitous mixing of the three (so-called) 'primaries', red, blue and yellow (or even cyan, magenta and yellow), we start learning about colour by seeing.

Revitalised foundational colour curriculum

The 'Eye-opener' series

Our beginning exercises focus on the contextual nature of colour. The study of colour and context is not traditionally done at the foundational level. However, noticing how perceived colours change with their context – be it due to the surrounding environment, the illumination source, the distance – is a big eye opener and a good way to get teachers (and their students) interested in learning more about colour. We start with the Koffka Ring (see Figure 1). Teachers cut out and separate the two halves and are immediately intrigued by the effect. We chose to render the Koffka Ring with greyscale – it prompts questions like: Is grey a colour? What are colours? These types of questions can promote an early discussion on the nature of colour attributes, and expand awareness that the term 'colour' is not synonymous with the term 'hue' (a common misconception).

Figure 1: Koffka Ring (left) and Koffka Ring separated into two halves (right).

This approach is a fundamental shift away from the way colour is traditionally taught. We focus on noticing and describing the perceptual experience. We do not give complex conceptual explanations at this foundational level – these can come later. Subsequent exercises include exploring Simultaneous Contrast (Figure 2-left), the Munker-White effect (Figure 2-right) and afterimages. Students use crayons, markers, coloured papers to create these illusions. Physically laying down one colour from a crayon, and noticing and describing how the perceived colour changes depending on its environment is engaging for students of all ages, including young children. It is important to spend time with these illusions, and notice and describe the perceived colour differences. At first glance, some teachers thought that simultaneous contrast and the Munker-White effect appeared to have the same effects, however they do not. Figure 3 was designed to illustrate the clear difference between the role of context in simultaneous contrast (top) and the role of assimilation in the Munker-White effect (bottom).

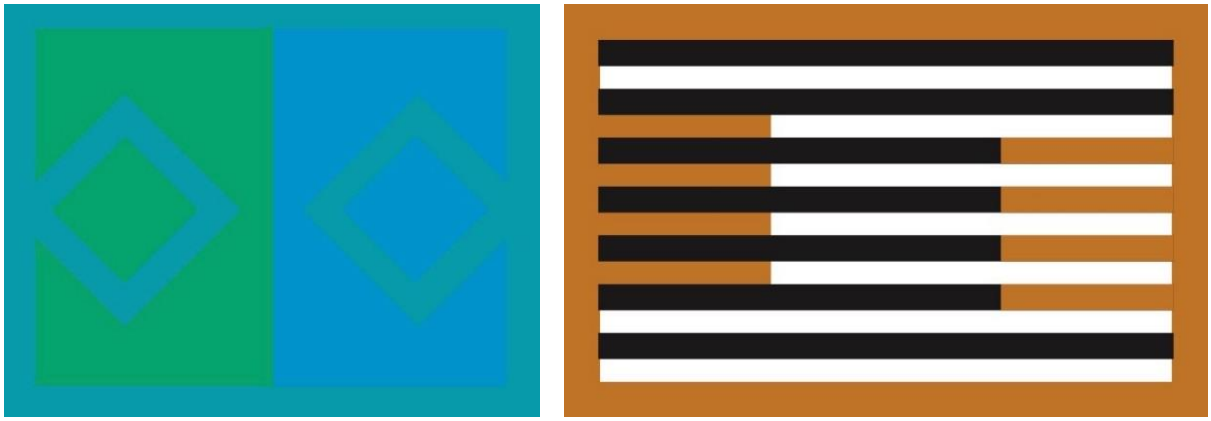

Figure 2: An example of simultaneous contrast, where the central diamond shape's perceived colour in influenced by the surrounding background colours (left). An example of the Munker-White effect, where the horizontal bands of black and white impact the perceived lightness of the brown surrounding colour (right). Illustrations courtesy of P. Green-Armytage.

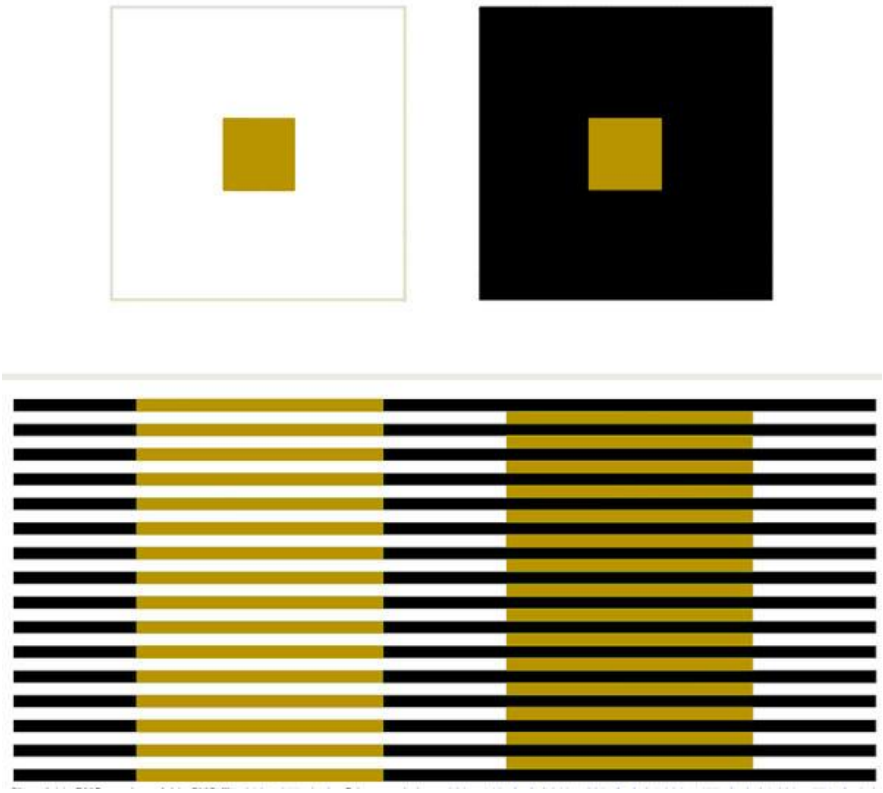

Figure 3: A comparison of simultaneous contrast (above) and the Munker-White effect (below) using the same colour. Note that the lightness of the dark yellow areas is affected in the opposite sense between the two illusions (i.e. the yellow appears comparatively darker on the top left when surrounded by white in the simultaneous contrast example, and comparatively lighter on the bottom left when juxtaposed with white in the Munker-White example). Illustrations courtesy of M. Maggio.

We further look at how context impacts perceived colours with an exercise where a 3-dimensional cube is constructed from a solid-coloured print-out (see Figure 4). Teachers notice and describe how the different sides of the cube appear: How are the colours different? How does the lighting source impact the perceived colour? The physicality of building the cube from a single colour, and noticing and

describing how it changes cultivates proficiency of both seeing and describing colour variations. Another exercise focusses on noticing and describing how perceived colours change with distance. These introductory exercises provide simple and effective ways of deepening and broadening the visual experience, increasing the ability to articulate about those experiences, and can be used at any age level. Colour becomes a rich and expansive topic if the focus is not solely on how colourants mix.

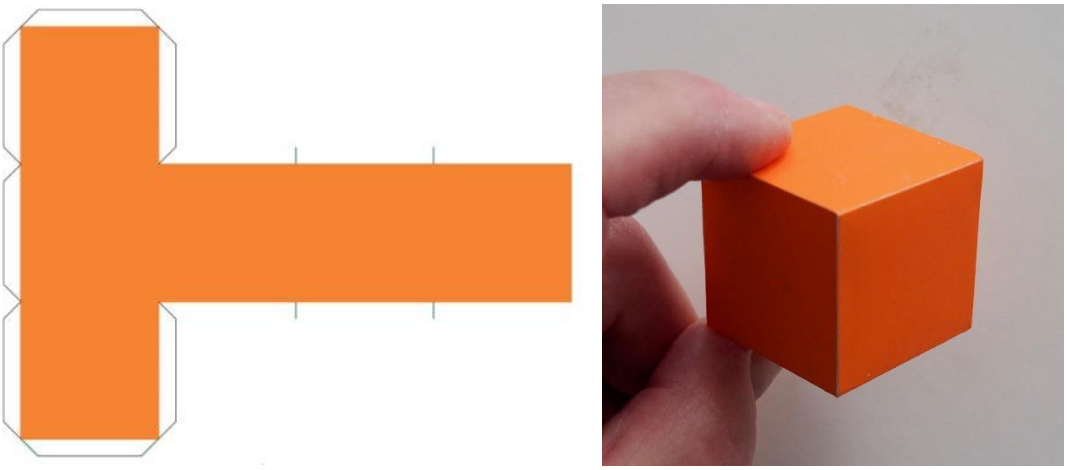

Figure 4: Template for cutting out and building the orange cube (left) and the built cube (right). Right image courtesy of P. Green-Armytage.

The second section of the Eye-opener exercises involves sorting coloured tiles. We have created both physical [18] and digital [19] sorting sets. The sorting sets contain 45 distinctly coloured tiles, based on nine hues with four variations (or 'Characters') per hue and nine achromatic tiles. The sorting set is described in Green-Armytage & Maggio [18; see their Figure 2 for the precise colours used in the physical sorting set]. See Figure 5 for the chromatic tiles used in the digital set. The full series of sorting exercises is described in detail by Maggio & Green-Armytage [20].

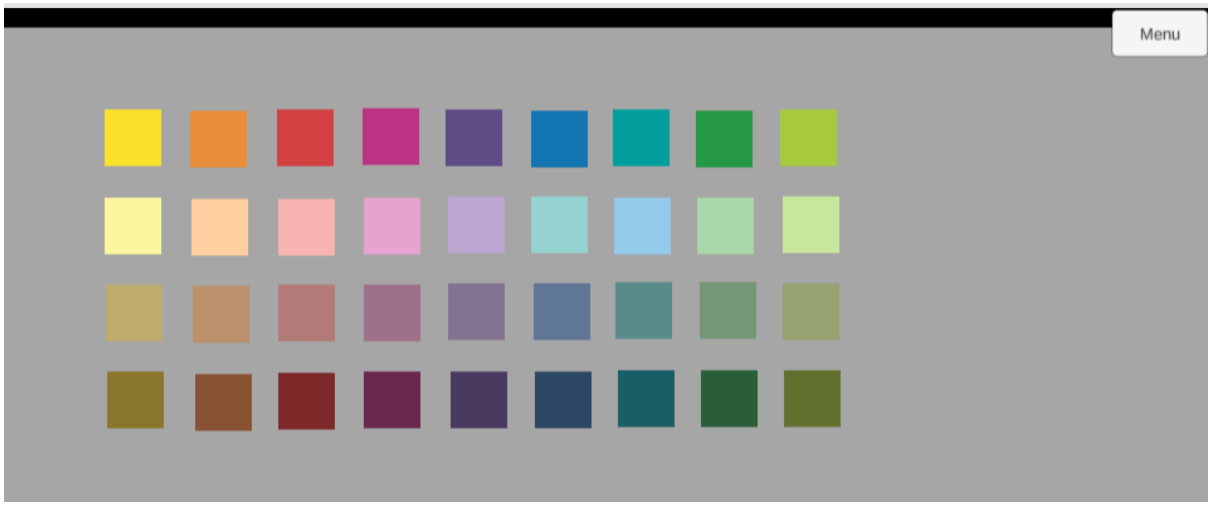

Figure 5: Chromatic tiles used in digital sorting set: nine hue families (columns) with four characters (rows) per hue family - vivid, pale, muted and dark (top to bottom).

In our foundational exercises, the term 'Character' is introduced to encompass vivid, pale, dark and muted variations for a given hue. Much of introductory colour education focusses on working with the vivid hues only, which creates a limited experience of colour, and adds to the misconception of equating

colour with hue. One of our goals is to move away from this hue-focussed paradigm for colour [21] and emphasise the richness of other colour attributes. Since we have spent time looking and noticing colour variations in our environment in the introductory Eye-opener exercises, teachers are better able to notice and describe the variations within a given hue. We have found that the teachers and their students – even young children - are easily able to understand and use this terminology.

The sorting exercises begin with a 'free-sort', without specified sorting directions, to allow the teachers to arrange the coloured tiles however they wish. This promotes a good discussion on why they made their specific arrangements, and how they relate to colour on a personal level. Following this exercise, one of the teachers at a training session discussed her synesthesia; this type of sharing of personal responses to colour highlights the benefit of an open, experiential approach.

Subsequent sorting exercises focus on recognising and organising colours according to their Hue Families (which are vivid, muted, pale and dark variations for a given hue; see Figure 6-left), Characters (see Figure 6-right), and recognising and arranging the colour attributes of lightness level and chroma. The optimal foundational level terminology for teachers regarding colour attributes is being investigated. In our first round of teacher training, we took the approach of waiting to see which words the teachers spontaneously used for the colour attributes. However, after these introductory training sessions, the teachers made a clear request to be provided with vocabulary which is simple to understand, and does not contradict itself at higher stages of learning. With the current round of curriculum testing, we are testing the terminology *hue*, *lightness level* and *chroma* for colour attributes, with alternate descriptors like value for lightness level (see also [20] for an expanded discussion). Most likely multiple words and definitions will benefit most people and styles of learning. With each set of exercises, we provide appropriate vocabulary lists with visual illustrations, and give both basic and advanced definitions.

Figure 6: Coloured tiles arranged to show the grey scale and the nine hue families (left). Coloured tiles grouped according to their character: pale, muted, dark and vivid (right).

Following the sorting exercises with coloured tiles, the next exercise is to collect coloured objects from a particular hue family around the house, or in nature, and then arrange them according to their colour characters. This engaging exercise deepens attention to colour variations of objects in our environment, and fosters chromatic acuity. The teachers photograph and post their images on an online virtual bulletin board like *padlet*. We found that sharing and viewing the collections of objects together as a group stimulated very engaging discussions about the nature of colour.

The third section of the Eye-openers involves constructing 3-dimensional models with colours arranged according to their colour attributes. Here we use at least two different types of colour models, so the teachers can understand there is not only one way to organise colour. One teacher found the 3-D

arrangement of colour in itself to be a complete revelation; she had never considered that colours could be arranged three dimensionally. Some other teachers commented that the use of more than one model helped them understand the complexity of colour; they had not realised that the way colours can be arranged is not unique. The concept of the *elasticity* of colour space [22] is introduced to explain why there can be many different forms of these 3-D models. Another teacher with limited colour vision (see below) found that one model (designed by Andreas Schwarz) made much more sense to him visually than the other model we used (Kolormondo®). Using multiple 3-D visualisations for colour had unanticipated benefits.

The 3-dimensional framework for organising and arranging colours is a foundational cornerstone for 21st century colour knowledge, and is often not included in current teaching of colour (see section on Survey results above). With these Eye-opener foundation exercises – which are for everyone, not just artists – we establish a fundamental colour knowledge base for all students, and can later build on these ideas for using colour within an art and design practice

The 'STEAM' series

In the second series of exercises, we put colour into a STEAM – Science, Technology, Engineering, Art and Math – framework. By approaching colour foundations with an interdisciplinary lens, we re-frame colour education as being not just part of an art class. The STEAM exercises begin with looking at the spectrum produced by a CD or DVD, objects which are readily found around the house. A common misconception is that there are only the seven colours in the spectrum as described by Newton: ROYGBIV. By looking at an actual spectrum and also looking at a high-quality image of a spectrum, teachers see that we can perceive many more colours (or hues) than these 'famous' seven.

The STEAM series also includes exercises that involve making and observing iridescent colour, with bubbles and thin films of clear nail polish (see Figure 7). The topic of structural colour is usually neglected in traditional colour studies, yet is the mechanism behind many intriguing colour phenomena. We use structural colour as a way to experience the non-spectral magentas and purples; teachers soon realise that not 'all' colours (or hues) are present in the spectrum (another common misconception). Although magenta is not one of the eleven basic colour terms of Berlin and Kay [23], it nonetheless is a prominent colour in today's fashion and toy industries, and present in many everyday objects. Being able to name magentas and distinguish them from pinks is an important foundational component of 21st century colour knowledge.

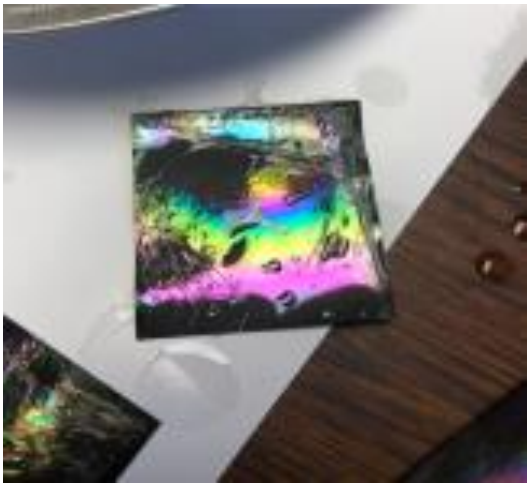

Figure 7: Iridescent paper created with a thin film of clear nail polish. Image courtesy of M. Maggio.

Additional STEAM exercises use inexpensive sets of coloured LED flashlights and coloured filters. Light beams can not only be used to demonstrate the additive mixing process (see below) but also used to explore how coloured light beams impact the perceived colour of an object. The filter sets contain coloured filters as well as diffraction gratings. The diffraction gratings can be used to create additional spectra for the first STEAM exercise, as well as to look at various light sources. Teachers can explore their environment and notice that different types of light sources have different spectra (or different colours or patterns of colours present). The coloured filters can be used to examine how white or other coloured light beams change colour as they pass through the filters, and to create other sources of coloured light beams outside of the LED flashlight set. The filter sets also contain filter transmission curves which are useful to help visualise the relation between spectra and perceived colour, which can be discussed at higher grade levels.

Our final set of STEAM exercises involves comparative mixing. Rather than creating a colour wheel, the teachers mix a variety of colourants of the same perceived colours (like blues and yellows), using a variety of mixing processes. We emphasise mixing many variations of neighbouring hue families and characters. For example, using slightly different blue-coloured chalk pastels with the same yellow-coloured pastel can produce a variety of subtractively mixed greens; these greens in turn can be made into pale, dark or muted variations by mixing with black and/or white- coloured pastels (see Figure 8). The same exercise can be done with paints. We are moving away from the overly simple and misleading statement: 'blue and yellow make green'. Instead, the focus is on using various blues and yellows, and how they can produce a rich variety of greens, and further how we can describe those greens in terms of their hue families and characters. However, if we choose the same colourants but use a different mixing process, the mixed colour is not necessarily green. Introducing mixing by comparing different mixing processes with many types of media, attunes teachers to colour's complex and multi-faceted nature.

Figure 8: Different blue and yellow- coloured pastels subtractively mixed to a variety of greens. Image courtesy of M. Maggio.

Another comparative mixing exercise focuses on creating mixtures via the partitive or additive-averaging mixing process using spinning disks. The centre of a disk is painted with a subtractively mixed colour of paint (for example, a green mixed from blue and yellow- coloured paints), and the outer edge of the disk is painted with alternating band of the two component colours (see Figure 9). When spinning the disk, the optically mixed colour is clearly different from the subtractively mixed colour: often an

achromatic grey vs. a dark or muted green. For some choices of blue and yellow, a spinning disk can even produce a pink colour, as discussed by Green-Armytage [24, see his Figure 19]. The process can be repeated, with different blue and yellow- coloured paints, different media, other colours of paints, and different patterns and ratios of colours on a disk. This open-ended approach allows teachers to explore the process in a variety of ways and gives strong visual evidence for how these two mixing processes yield different results for their mixed colours. This exercise is both fun and exciting for young children, and also can also be structured as a more formal exercise using the scientific method for students at higher grade levels.

Figure 9: Set up for spinning disk exercises. Image courtesy of M. Maggio.

The simple additive mixing process can be demonstrated using the coloured LED lights or filters. Here blue and yellow-coloured light beams can be mixed additively to yield an achromatic (white) light beam (see Figure 10-left), and compared to the colours obtained by mixing other blue and yellow coloured media via the subtractive and additive-averaging processes. The filters can also be stacked, and used to produce a subtractively mixed green (see Figure 10-right).

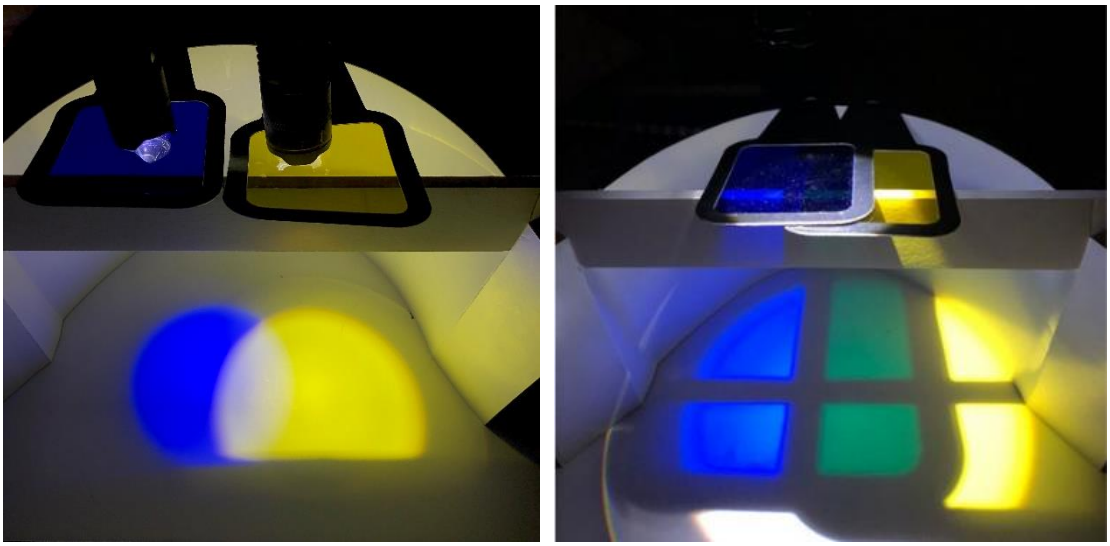

Figure 10: Combining separate blue and yellow-coloured light sources demonstrates the additive mixing process (left). Shining a single light source through stacked blue and yellow-coloured filters demonstrates the subtractive mixing process (right). Images courtesy of M. Maggio.

The final series of exercises in the STEAM series is an examination of device dependent colour. A microscope is used to examine a variety of greens rendered in different media – from printed images to digital images on phones, laptops, tablets, etc. Colour display applications are also used to determine the RGB or Hex digital compositions of the greens. This is a complex topic to understand at the foundational level. However, due to the ubiquitous presence of digital displays in our daily lives, exposure to the idea of device dependent colour variations is important at an early age. Even young children notice colour differences between the same image displayed on a variety of devices.

Addressing variations in colour perception

Recognising and accommodating students with colour vision deficiencies is a component of colour education which is not usually addressed. Our preferred term for this condition is 'limited colour vision' (moving away from the misnomer colour 'blindness'). Teachers need to be aware of the demographics of potential perceptual diversity in their classrooms, and be equipped to best support their students. Studies have shown that 8% of males may have some kind of limited colour vision [25] where they perceive a limited range of colour (but are not completely 'blind' to colour). Indeed, in three of our test schools, at least one teacher has had limited colour vision. In our teacher training sessions, we discuss how this condition may limit the colours seen by some of the students in the class, and provide alternate or modified exercises for these students. For example, in the sorting exercises, the achromatic tiles can be removed by a student with limited colour vision, who then works with their individual chromatic palette. The student doesn't need to ask their neighbour about the 'right' way to sort or arrange colours, as their results are not 'wrong'. Colours are perceptual experiences, so the way one sees colour is the way one sees colour – there is no 'wrong' way to perceive. Students thus engage with colour through their own lens, ultimately resulting in a more meaningful and deeper learning experience, as they cultivate their own personal relationship to colour.

Preliminary results of testing the revitalised colour curricula

The Eye-opener series was introduced to teachers in our first stage of curricular beta-testing at St. Teresa's R.C. Primary school in Salford, England and Clinton Public School in Toronto with a series of workshops in 2021. The second series of workshops focussing on STEAM activities was presented to St. Teresa's teachers in early 2022. We have expanded our beta-testing to middle and high schools, and are currently running our second beta-test series at Da Vinci Middle School in Portland, Oregon and Morristown Beard School (a middle and high school) in New Jersey.

Following our first beta-testing workshops with primary school teachers, we then conducted surveys and interviews to ascertain how the teachers responded to the workshops, what could be improved to help their learning, and what specific supports they would need to bring the activities into their classroom. Our initial thought was to merely provide resources for teachers, but following the surveys and interviews, we recognised the importance of also providing specific exercise modules for students which could easily augment and/or replace the existing curriculum. In addition, some teachers felt that they lack the confidence to bring this new material to the classroom, which prompted us to develop our Teacher Guide, with a glossary, as well as specific ideas for lesson plans with learning outcomes. We have developed background resources for teachers to deepen their personal knowledge base, and be more successful at bringing this material to their classroom. This feedback from the first stage of beta-testing was incorporated into our Teacher Guides, which we are now using in the second beta-test series.

One important result of our first beta-test series was the recognition by teachers and their students that colour was much more than hue: by moving from working with hues into working with hue families with all their vivid, muted, pale and dark characters, and by moving from a 2- to a 3-dimensional view of colour, both teachers and students considered their visual worlds to be substantially widened. When the teachers of St. Teresa's school introduced the sorting sets to their classes, they immediately noticed that the children (ages 3-11) had very few descriptive words for colours, other than light and dark. The teachers responded by helping their students expand their language around describing colour with descriptors like butter-yellow, daffodil-yellow, etc., as well as introducing them to the colour character terms and idea of hue families. The Year-4 (ages 8-9) students created a wonderful colour dance, to physically express the differences between the vivid, pale, dark and muted colours with their bodies.

Additionally, the teachers of the older children (ages 8-11) found that this age group did not have a more advanced vocabulary about colour, compared to the younger primary children. The teachers commented that this was unusual, because in most subject areas like math, students build and compound their vocabulary as they progress through to higher grade levels. This points to the minimal role that colour plays in primary/elementary school education, and emphasises the need for a scaffolded approach for foundational colour education.

The teachers at St. Teresa's school spread their enthusiasm for our colour workshops with their school, and devoted International Colour Day (March 21, 2022) to colour related activities and projects across the entire school, and shared their projects on social media (see Figure 11).

Figure 10: Children from St. Teresa's R.C. Primary school in Salford doing colour literacy activities. Image courtesy of C. Harrison (left) and S. Wilson (right).

Next steps

Our second beta-test teacher training series is ongoing with Morristown Beard School. We are looking for other schools who would like to test our curriculum. We are also developing further curricula related to digital colour, and expanding our multi- and interdisciplinary approach to add modules on the social and cultural aspects of colour, which are key for 21st century colour education foundations.

One challenge that we are encountering is that elementary through high school teachers have very demanding workloads, and extreme time constraints on their schedules. They often have limited time for teaching about colour, which is generally taught as a yearly module within an art class. Although we cover a large number of topics in our teacher training, the teachers are not able to cover all the material in their classes. We are tailoring some exercises to fit within shorter lesson-plan timetables, as well as

creating pathways for learning, so depending on the time available, a smaller number of exercises can be done and then later revisited in more depth at higher grade levels.

We are also developing more background material for teachers, to support and enhance their knowledge base, so they can feel more confident when bringing this new approach to colour into the classroom. One common comment about introducing STEAM curricula into the classroom is that although teachers may be keen to bring new material to their students, they have many demands on their time, and cannot devote the time required to put together new lessons with new curricula as well as improve their background knowledge. 'Pedagogical discontentment' is a measure of the gap between a teacher's own goals for their teaching, and their actual classroom practice. Boice et al. discuss how pedagogical discontentment is common for subjects taught within a STEAM framework, but decreases with appropriate training and support [26]. One of our ultimate goals for the Colour Literacy Project is to develop videos for our teacher training, so teachers will have easy access to the appropriate background material, and feel better prepared to adopt our revitalised approach to their classrooms.

Conclusion

The Colour Literacy Project's approach for teaching the foundations of colour to all students has been met with positive responses by teachers who have participated in our teacher training sessions. Both they and their students have found the foundational exercises to be exciting and engaging, while stimulating a new way of thinking about colour. We are encouraged by these results and are further testing exercises, optimal vocabulary and verifying our overall pedagogical approach. We welcome input from other educators. Revitalising colour foundations is a crucial step for bringing colour education into the 21st century.

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