The development of artists’ novel colour palettes for inkjet printing

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ABSTRACT

In this changing environment in which the artist and designer has access to a wide range of digital imaging tools and technologies, that on first glance, are dedicated to the creation of colour mixtures, why is the digital interface and colour outcome often disappointing? It appears that hardware, software tools and methods for digital printing are not necessarily suited to the specific requirements of the artist. In fact, they are too generalised to obtain a high degree of quality and too inflexible to allow artists to obtain precision and predictability. Is it possible for an artist to mix and print a colour that captures their creative imagination? The motivation for this research is based on how artists mix and print colour by traditional means (painting and printmaking) and how these differ from colour picker tools, slider bars and methods developed for digital printing, and whether it is possible to incorporate both? The paper provides a brief historical background to artists who have developed colour systems to assist their particular colour choices. Based on existing hardware and software, the paper suggests alternative approaches to colour selection, demonstrates methods for the creation of novel inkjet printed palettes, and how these can be visualised and compared.

Keywords: Colour selection, inkjet printing, novel colour palettes, alternative gamut

2. INTRODUCTION

Artists have been experts in mixing colour for centuries. However, as digital technologies have become ubiquitous, artists are obliged to use digital tools that may not be appropriate for the job. In fact, standard digital devices with standard colour mixing are subject to severe gamut constraints, which is a new problem for artists who are used to direct mixing and printing with pigments.

For artists, the approach to formulating a colour palette is based on the relationship between the appearance of colours in a scene and mixing pigments according to the colours in the scene. The artist might employ a range of decisions based on formal training, an understanding of colour theory, interpretation, emotion and aesthetic choices, or as John Gage in Colour in Art explains, those decisions may reflect the ‘creative imagination of the artist’. However, for digital colour methods of mixing and creating palettes, the artist may be able to employ many of their traditional skills, yet these digital methods for transferring colour from screen to paper are neither direct nor controllable. It is very likely that artists can explain the difference between subtractive colour mixing and additive colour mixing, yet might be less familiar as to how different values of red, green and blue (RGB) can be added to obtain a particular colour, and furthermore, how cyan, magenta, yellow and black inks in a printer (CMYK) are colour managed within the digital printing pipeline.

The question might be asked, “Are not the existing process colours enough?”

With the advancement in digital printing technology development, colour inkjet systems have been developed to print more than four colour inks. Light cyan and light magenta have been used as a way of smoothing the scale from the mid tone to the lightest tone. In the past, a range of other process colour solutions have been added to the existing colour set to extend the printable gamut: orange, green and purple red, green and blue or spot colours for commercial printing. Eleven-ink colour printers are now incorporating inksets that address the reddish-orange, purplish-blue, greenish-turquoise regions of the gamut, as well as a range of greys and photo blacks. For the task of calculating the colour gamut of an 11-ink printer, according to literature, introduces an interesting challenge to device characterisation techniques.

These suggestions remain additions to existing CMYK colours. As Hardy and Wurzburg hinted in 1948, a new printing process might include a system where the printing of colours was not dependent on the use of process colours. Hardy and Wurzburg suggest:
It is of interest that, regardless of the number of impressions, the inks may be selected solely on the basis of their color gamut. Their colors need not be cyan, magenta, and yellow; nor is it required that they be transparent. The way is therefore opened for entirely new printing processes. 7

However, the answer is clear in the comparison between a traditional hand printed screenprint that might involve only a few mixed pigment colours, and an inkjet print using process colours. Although the CMYK process colour range may occupy a larger area of the colour spectrum in order to satisfy naturalistic requirements, the screenprinter may require a very selective palette of a few colours. The addition of more process inks does serve to expand the colour gamut of the printer, and brings it in line with the capabilities and flexibility of commercial printing, such as offset litho. However, if considered for the production of fine art quality prints, it still does not adequately address the shortcomings of traditional modes of colour mixing and printed colour as used by artists.

The following chapter considers the hypothesis of working with a traditional artist’s colour palette. With a range of hue colours such as purple, green, yellow, blue, red, it may be possible to develop colour sets that create mixtures more closely related to an artists’ colour paints. Although this may present a much reduced colour gamut in comparison with the standard CMYK system, it is possible this method may access unique colour combinations and blends that have been explored by artists, for example, browns, dark blues and ochres. The intention is not specifically to expand the gamut but to distort it: to propose new ways of colour mixing in order to provide new tools for colour mixing that is more intuitive, direct, and makes a connection between traditional modes of colour mixing and the digital translation of these colours.

3. THE ARTISTS’ PALETTE

From the 14th century onwards, colour theories were developed for the artist’s palette, involving both the observations of natural phenomena and the ways pigmented colour could be mixed and applied. The challenge for artists in determining precise methods for mixing, selecting and applying colour is described in early publications such as Il Libro dell’Arte (The Craftsman’s Handbook) by Cennino Cennini written around 1390, provide practical advice, for example, which colours to choose to describe the folds of drapery.8 Alberti’s book, Della Pittura (On Painting) (1435-6) provides an early insight into the phenomena of colour, for example, how colours interact when placed next to each other. The following selected examples highlight the artists’ particular requirements and their colour systems and codings.

3.1 Jacob Cristoph le Blon (1667-1741)

Le Blon devised a method for combining three coloured mezzotint plates of red, blue and yellow in order to produce full colour reproductions of paintings.9,10 Although Le Blon invented three-colour printing, he was solely concerned with the pragmatic application of printing with pigmented inks, and never undertook to develop his own organised colour-system. However he did theorise on colour in Coloritto (1725)11 on the colours and the methods required to achieve a full colour image, and which remains the basis for colour printing today. Le Blon described the three fundamental requirements to recreate a full coloured image:

- the inks had to be translucent for the colours to properly mix;
- the inks had to be of a similar density to provide a balanced image of which no colour was prominent;
- and the colour printing process required a continuous tone method for them to mix.

Le Blon’s suggestion that colours need to be translucent conflicts with Hardy and Wurzburg, yet demonstrates the need for the different requirements of the printer.

3.2 Moses Harris (1731-1785)

Harris, engraver and entomologist, was possibly the most significant butterfly and moth colourist in the 18th century. He was influenced by the work of Sir Isaac Newton (1642-1727),12 but was also interested in Le Blon’s theories on subtractive colour, or as Harris described, ‘by the painters art’. His requirement was to create a precise colour index of colour pigments that was based on his empirical observation and depiction of the natural world. In 1758 he started work on his major publication, The Aurelian or Natural History of English Insects (1766) (figure 3),13 which included forty-five engraved plates with hand water colouring. In his work the Natural System of Colours (1766)15 he demonstrated how secondary colours could be produced from red, yellow and blue, and that black could be obtained by the superimposition of the three basic colours.
Moses Harris’s colour circles showing primary ‘prismatic’ hue colours and secondary ‘compound’ colours, from *The Natural System of Colours* (1766) \(^\text{15}\)

Figure 3 shows the frontispiece to Moses Harris *The Aurelian or Natural History of English Moths and Butterflies* (1766)\(^\text{13}\), and in Figure 4 Plate number 38 entitled Bees in Moses Harris, *An Exposition of English Insects* (1782)\(^\text{14}\).
He introduced two colour-charts of symmetrically segmented circles of primary and secondary colours, with complimentary colours opposite each other: red-green, yellow-purple, and blue-orange (figures 1 and 2). He provides a long scale of tones of colours, which lighten by degrees to the outer edge. Although he described the colours in figure 1 as prismatic, the term was used to describe the primary colour pigment hues and not as we understand the term in relation to the colour spectrum. From the six colours, Harris recommended the mixing of each adjacent colour in such a way that one of these two components predominate in each case. Extending from the work of Newton and Goethe, he used the colours in nature as his source and provided a reliable colour palette and specification guide for the artist and illustrator. One can understand by looking at Harris’ scientific drawings that his methods for developing a high standard of colour accuracy were required for reproducing the hand colouring of insects from plate to plate.

3.3 Wilhelm Ostwald (1853 -1932)

Ostwald was an enthusiastic amateur painter and Nobel-prize winner for chemistry, and met Albert Henry Munsell (1858 -1918) in 1905. From his scientific perspective, Ostwald was inspired to create a colour theory that would enable him to create a systematic and accurate method for selecting colour to make his naturalistic landscape paintings. A ‘full colour’ circle (1916) was devised as a twenty-four segmented colour circle with yellow, red, blue and sea green as the primaries. He used the term ‘full colour’ which is the same as hue. Using a double colour cone, he also introduced the terms dark-clear and bright-clear to describe when colours were mixed with black or white. Ostwald also used spinning tops to obtain a perceptually correct colour balance. Possibly because of his interest in painting from nature, Ostwald paid particular attention to the green areas, which is interesting when compared to the CIE colour system, a greater proportion of the chromacity in the diagram is given to green, yellow-green and blue green.

3.4 Robyn Denny (1930 -)

Artists working in screenprint in the 1960s and '70s, utilising highly pigmented screenprint inks, explored the medium by experimenting with translucency, opacity, multi-layering, use of white, fluorescent and metallic inks and different patterns and tones to produce secondary and optical colour mixing.

In conversation with English painter Robyn Denny, who has been producing paintings and screenprints since the 1960s, Denny described his passion for colour. From his archive, he produced a hand mixed colour template, which were swatches of painted colour on paper, carefully arranged as a formal colour wheel, and designed to be a reference for his screenprints (figure 5). Chris Prater, master screenprinter of Kelpra Studio London, was able to mix and screenprint colours that matched Denny’s colour coded designs. The ratios of colours pigments were mixed according to Denny’s formulations and the transition from design using the colour wheel to paper was more precise.
4. CHOOSING COLOURS

The question therefore is what colour delivery system may best suit the specific needs of the artist? In commercial printing the method of representing a broad range of colours is based on the mixing capacity of a range of four process colours. The selection of the most basic ink four-colour system consists of process primaries that represent the mid-point between a red shade, blue shade and a yellow shade. Whilst this approach to colour mixing is used to simulate the many hues generated by those pigments, it does not give access to all the rich complex colours, such as burnt umber, that are accessible by mixing the variety of artist pigment colours. However, by employing the methods offered by this research, the artist can seek out a great variety of pigment colours that each offer very subtle differences, and when mixed with other colours will create many thousands of subtle hues, tones and tints. The artist engaging in traditional printing methods has the opportunity to add opaque whites, translucent bases or media that will change the viscosity, texture and the transparency of the colour.

As demonstrated by the paint chart (figure 6), there is a vast range of pigment colours available to the artist. The selection and mixing of colours to obtain a desired effect is based on the artist’s knowledge that an ultramarine blue mixed with a cadmium red results in a very different purple than, for example, a cobalt blue mixed with the same red. The artist will understand that in order to obtain a perceptual mix between two colours, more of one colour might be required, for example, in order to obtain an orange that is a perceptual midway point between a red and a yellow, a greater quantity of yellow paint is required than red. Unlike artists’ pigments, commercial CMY colour mixing is based on percentages of colour, as exampled in the Pantone colour mixing system, and which is emulated in the inkjet printing. With the advent of inkjet, recognised CMYK colour systems and language were appropriated and transferred from the offset litho and screenprint industry. Designers and printers working in the graphic and design industry - using all the prepress software, colour systems as used for offset litho and screenprinting - could easily make the transition to inkjet. Therefore, for these designers and printers who were used to working in a CMYK language, it is possible that the method was considered by the developers of inkjet machines as commercially expedient for continued use. There was however, a missed opportunity by the developers for an alternative approach that could be employed using actual or spot colours instead of process colours. Whilst more time-consuming in its initial stages, this might have paved the way for an altogether innovative approach to colour mixing.

Figure 6. The range of water-colour pigments as produced by Windsor and Newton for artists. These hand painted colour swatches onto watercolour paper demonstrate their opacity (at the top of the swatch) and translucency (at the bottom) and particular qualities such as granularity and ability to produce washes and gradations of colour.
The suggestion therefore is to devise a colour mixing system that incorporates six hue colours (in addition to a black and white). Hue colours between each of the mid-points could be utilised; for example, a yellow shade of blue, which tends towards a hue that is more greenish, or a yellow shade of red which tends more towards orange. By using colour pigment hues, similar colours are described as: cadmium yellow, cadmium lemon, French ultramarine blue, phthalo blue, permanent rose, cadmium red. These colour terms, of course, differ spectrally from one manufacturer to another, but have provided a well utilised and recognisable language among artists.

4.1 Practical training in inkjet head filling

The intellectual property rights of inks for inkjet and inkjet heads are strongly defended by manufacturers. In order to proceed with my research and my requirements for developing custom inkjet colours, HP allowed me the rare opportunity of learning highly confidential methods in the filling of inkjet heads, at the inkjet formulation division at HP Labs in San Diego. The manufacture of inks and heads involves rigorous and scientific testing procedures and conditions. After training at HP Labs, a number of tests, modifications and fine tuning were undertaken by me in Bristol to ascertain and perfect a method for filling inkjet heads. This included the filling of cartridges, sealing, purging of trapped air bubbles, and disconnecting the cartridges from the main printer pipeline. The latter was to ensure the inkjet feed-pipe system did not require re-purging and renewing whenever a new colour was added.

4.2 Refining ink combinations

Early experiments into the creation of colour charts involved the use of a range of artists’ drawing ink colours. However, as the inks contained tiny particles and the print head nozzles quickly became blocked, it was decided to initially use HP dye inks, as these already had the guaranteed purity for inkjet printing and could be mixed without the problem of clogging. This has advanced to the use of pigmented inks and has presented a much-desired proof of concept that dye based machines and print heads can be modified for pigment inks.

As each ink colour was mixed, draw-downs of mixed colours were made (figure 7) and then measured using a spectrophotometer. Each new colour was printed, measured and compared to the draw-down measurement; this was to ensure that the method of pre-sampling of the hue colours could be achieved without the need to print every mixed colour. As new ink combinations were mixed, the same method was used. The ink ratios were also recorded so that the inks could be mixed again. The experiments sought to produce light and dark colour combinations of each new hue colour (figure 8), ideally resulting in a smooth tonal transition from light to dark, with visible printed colour information in the light areas. Furthermore, by creating ICC profiles from the printed colour charts and viewing the measured colour in a three-dimensional space, it was possible to gain an overview of the relationship between a generic CMYK gamut and the newly mixed colours, for example, where these mixed colours might extend the limits of the existing CMYK colour gamut.
As tests progressed, colours and colour combinations were fine tuned, and the print heads were rearranged according to their most appropriate placement in the printer. The initial objective was to ensure a smooth transition between light and dark colour pairs, therefore the placement of the inkjet heads reflected a similar positioning to existing CMYK inks: a cyan and light cyan might be replaced by a green and light green or a blue and a light blue; the magenta and light magenta might be replaced by a red and an orange. However, as exampled when working with artists Ruth Piper as described in 2008, the channels could also be used separately, which resulted in a more blocked appearance to the colour chart.

4.3 Colour print hardware

Tests were conducted on two 24” HP 130nr RGB printers, which have a roll-feed and are capable of printing 2400dpi horizontal resolution and 1400dpi vertical resolution. The printers have six-colour channels: cyan, magenta, yellow, black, light cyan, light magenta. One machine remained unmodified to print cyan, magenta, yellow, black, light cyan, light magenta inks and is referred to as the cmyk printer; the second printer was used for experimental/novel inksets and is referred to as the custom printer.

In order to over-print colour, and based on experience of using the HP130, this machine was quite accurate (to one pixel) in reloading and over-printing colours (however, a white frame was needed around the image to allow the sensor inside the printer to track and find the edges of the sheet. If an image covered a whole sheet, the machine would reject the paper). Previous experiments in multiple printing at the CFPR have included the development of a pin-register system for the HP5500; by isolating the paper feed mechanism though the use of switches, very accurate re-registration can be achieved. However, due to the construction of the paper coating and the water levels in the ink, printing over large areas was found to cause the paper to expand, and therefore a few hours were allotted to dry the paper between printings. The same procedure was subsequently adopted for these tests.

4.4 Practical colour print experiments

A series of practical print tests were devised to test the relationship of mixed colours, in particular to test:

- The smoothness of transition of tone and colour.
- The transition of the lightest to darkest colours, when layers were over-printed.
- The final appearance of the different colours relative to each other when printed.

From these practical print tests, the data provided the artist with:

- A range of printed colour charts that showed the gamut of the inkset on paper.
- An ICC profile enabling the user to reference how the printed results would look while working on the screen.

In order to visualise the printed colours and to create the ICC profiles, an industry standard TC9.18RGB type colour chart format was adopted. This chart uses a ramp progression of colour squares that contains equal percentages of colour mixtures within a 3x3 grid of 9x9 colour patches and includes all the primary and light colours (figure 9). The colour patches outlined in red and labelled as A and B, illustrate the position of each of the primary hue colours (figure 9 middle...
and right) with each corner of the square equal to 100% of each colour. In the patches in the top left hand corner (A), the hue colours are red, yellow, green. In the patches in the bottom right corner (B), the hue colours are magenta, cyan and blue. A 100% black patch appears at the top left of the target (in block A) and a white patch (which contains no ink) can be located at the bottom right (in block B).

The inclusion of colour pairs was to emulate the existing light and dark system that is currently employed for cyan and magenta and their lighter colour versions. The objective was to ensure a smooth transition between white to full hues and also between the hues themselves. For example, in the same way a light cyan is used to print lighter areas of a cyan, so a violet or a blue requires lighter companions in order to produce the subtlest range of hue mixes. Therefore for every 100% hue colour, a lighter version was mixed to obtain a range of what we will term colour pairs: blue and light blue, purple and light purple, rose and light magenta, red and orange, green and light green.

4.5 Creating and printing the custom mix colours

Working from the shortlist of primaries as described in 4.4 a series of colour charts were created. The combinations of the mixed hues and lighter colour pairs were based on traditional hue colours that are more recognisable for use by artists. Ten different colour charts were printed on to high-quality fine-art inkjet coated paper and named as:

1. rose-purple-dark yellow; 2. rose-purple; 3. red-purple; 4. blue-green-black; 5. red-green-black; 6. red-green; 7. rose-green; 8. red-blue; 9. rose-blue; 10. green-blue.

The titles of the charts indicate the primary hue colours of each chart, and are shortened versions of the six ink colour sets, for example: the primary hue colours of chart number 5, contain red and green, light red, light green, yellow and purple.

For each of the colour combinations a TC9.18RGB colour target was printed, and measured using a Gretagmacbeth Spectrolino spectrophotometer on a SpectroScanT X-Y measuring table; the illumination was set to D50 and observer angle set to 2 degrees; the LAB data imported into ProfileMaker. Once the ICC profile was generated, the profile could be viewed using the Apple ColourSync Utility to compare the new inks to the standard HP CMYK inks; to visualise how the gamut had changed and to indicate what was gained and lost.

The chart could also be used soft preview the colours on screen and to obtain more consistent predictability of the appearance of the printed ink on paper. The ICC profile that is generated from the coloured chart is used to assist in driving the colours accurately from image file to printer. The measured data could also be used to make comparisons between the existing CMYK colours and newly mixed colours, or to make a comparison between any two colour charts (figure 10).

An artist wishing to use this system would have at his or her disposal a printed colour chart demonstrating the printed colour patches on a particular paper, the corresponding ICC profile (that would be uploaded to the Colour Profile Library on their computer hard drive), and a colour selection chart that could be accurately viewed in Photoshop.
5. VISUALISING AND COMPARING THE MIXED INKS

A further objective was to provide a precise comparison between the colour gamut of the standard HP 130 ink colours and the custom colours (section 4.5). The custom mixed colours were printed on the same hardware, measured and then by plotting the points of the cyan, magenta and yellow on a 3-D axis to create a three dimensional cube. The cube is practical for presenting a visual comparison between the original measured coloured patch and the corresponding colour patch measured from the new custom colour chart. In order to make an accurate comparison, an ICC profile was required. The following figure 11 illustrates the method used to convert the colours.

The HP 130 ICC look-up-table was used as the reference for conversion for any novel colour set. This profile was obtained by printing the original CMYKLCmLm dyes using the colour chart EC12002V CMYK, which contains 1485 colour patches. This was then measured and the profile was saved to the Colour Settings Library in Photoshop and used as the CMYK working space for converting the colours. In other words, when any colour was converted from RGB to CMY, the new profile 130cmyk (the original CMYKLCmLm dye colours used in the 130 printer) was used as the conversion space.

5.1 Plotting the original dye colours

Both the original dye colours and the custom mixed colour sets were printed using an RGB TC9.18 reference chart and the three 100% primary colour patches: Cyan, Magenta, and Yellow were measured and recorded as LAB values (see figure 9). The following process is presented in order to visualize geometrically the shrinking and/or stretching of the CMY space passing from the standard inkset to a custom version. The original dye colours referred as cyan (Co), magenta (Mo), yellow (Yo); are plotted according to a triplet of orthogonal axis in which a colour point p is plotted as:

\[ p = C_o + M_o + Y_o \]  

The points of the original dye colours of the Vivera inkset were plotted in the figures as red axes of a reference cube. The further vertexes of the cube are blue (Bo), green (Go), red (Ro), white (Wo) and black (Ko). The white point is the zero (0,0,0). As the same paper was used throughout, no white point shifts occurred. The other four points are:

\[ B_o = C_o + M_o \]
\[ G_o = C_o + Y_o \]
\[ R_o = Y_o + M_o \]
\[ K_o = C_o + M_o + Y_o \]  

5.2 Plotting the custom mixed colours

The colour patches corresponding to the custom dye colours were measured and the LAB values recorded. These LAB values were then converted in Photoshop to CMYK percentages using the 130cmyk profile as CMYK conversion space. The obtained value and the following plots have no colorimetric value since they are obtained after the Photoshop gamut mapping. The plots are presented to have a qualitative, but not quantitative, visualisation of the colour shift due to the ink
change. The extreme points of the custom mixed dye colours (C,M,Y,K,R,G,B,W) were plotted and represented in the reference inks CMY cube as a black-framed cube with black vector lines between each plotted point. The custom colours $p$ converted into the reference CMY space are plotted as:

$$ p = c_c \vec{C} + m_c \vec{M} + y_c \vec{Y} $$

(3)

where $c_c$, $m_c$ and $y_c$ are the relative amount of reference primaries after the gamut mapping.

In order to obtain the remaining points of the colour cube, the same calculations were made as the original dye colours so that:

$$ \vec{B}_c = \vec{C}_c + \vec{M}_c $$

$$ \vec{G}_c = \vec{C}_c + \vec{Y}_c $$

$$ \vec{R}_c = \vec{Y}_c + \vec{M}_c $$

$$ \vec{K}_c = \vec{C}_c + \vec{M}_c + \vec{Y}_c $$

(4)

5.3 Comparing the custom mixed colours

The following figures, 12 a-c, illustrate the complete method to visualising the mixed colour:

- The table listing the custom colours and a scanned reference of the printed chart;
- The measured data from the RGB TC9.18;
- The three dimensional plots to compare the CMY colours.

![RGB-CMYK colour chart: 6. red-green](image)

<table>
<thead>
<tr>
<th>HP Channels</th>
<th>Custom colours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>Black</td>
<td>Purple</td>
</tr>
<tr>
<td>Magenta</td>
<td>Red</td>
</tr>
<tr>
<td>Cyan</td>
<td>Green</td>
</tr>
<tr>
<td>Light magenta</td>
<td>Orange</td>
</tr>
<tr>
<td>Light cyan</td>
<td>Light Green</td>
</tr>
</tbody>
</table>

Figure 12a

![Figure 12b The side elevation and bottom view of three-dimensional gamut of the red and green colour chart](image)
The red and green colour chart as shown in figure 12, here one can visualise the relationship between the scanned reference of the printed chart (figure 12a), a 3-D colour three-dimensional colour plot based on the measured ICC profile (figure 12b) and three-dimensional cubes from different viewpoints (figure 12c) using the standard HP 130 ink colours as the conversion space (figure 11). The three-dimensional colour plot makes a comparison between the unmixed Vivera inks in the 130nr printer (as shown as the red wire frame cube, figure 12c) and the custom mixed colour set of red and green (as shown in the black wire frame cuboid). The graph shows four viewpoints: a top elevation, the cube in perspective, a front elevation and a right elevation. The position of the cyan, magenta and yellow axis provides an indication of the viewpoint. The cuboid in perspective and the top elevation, in this instance, provides a better picture. Here one can visualise how the red-green gamut closely mirrors the white to yellow axis, and then how it is squashed and stretched beyond the points G (yellow+cyan) and B (cyan+magenta).

**6. CONCLUSION**

In order to measure the colour and be able to preview how the colours appear on paper, an industry standard colour chart was used to compare measured colour data. For each of the newly mixed inks an RGB TC19 colour ramp chart was used to proof print all the ink combinations. The printed colour chart containing new colours was then measured and the profile used as the working space. The generated profile was also used as data for comparing ink sets, to analyse how the gamut had been compressed or expanded.

The printed colour charts demonstrated a wide range of subtle intermixable colours, which were printed onto a carefully selected fine art paper so the artist would have a better understanding of the visual effects of the printed ink on paper. The printed colour chart could also serve as a look-up-table, which enabled the artist to work in the same colour space as the novel colours selected for the print heads; to mix, select and overlay colours prior to printing.
Despite the limits of current colour management systems, the research has sought to utilise existing technology: inks, hardware and software, which have been adapted to produce alternative approaches for colour mixing and ultimately to present new perspectives on how colour can be printed and compared. Whilst, it could be argued, this approach is not the most precise and there are more appropriate conversion methods commercially available, an important objective was to appropriate existing hardware and software that could be adapted and be put to use in new ways and to seek alternative ways that utilise the technology in a more direct and creative way. This research has demonstrated that it is possible for an artist to appropriate existing software and hardware to create bespoke colour palettes and accurately print a chosen colour. For example a hue colour that can be described as Cadmium Orange by an artist could be mixed as an ink, a draw-down could be made and measured, a print head could be filled, a bespoke colour patch could be printed and measured. It could then be previewed on screen and printed exactly as the artist intended. This colour could then be mixed with a whole number of other colours and be accurately printed in the same way to achieve a new range of colours.

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