

The ambiguous term of "saturation"

Karin FRIDELL ANTER, Harald ARNKIL, Ulf KLARÉN
SYN-TES Nordic Interdisciplinary Network on Colour and Light

ABSTRACT

Ambiguous use of colour terms creates misunderstandings in the colour classroom, among professionals and in customer services. One obvious example is the term *saturation*. *Saturation* is not a common colour term in everyday language, but is widely used in the professional languages of art, design and science. There it has got several parallel definitions. In art and design parlance it most often refers to the "intensity" or "vividness" of a colour much in the same sense as NCS *chromaticness* and Munsell *chroma*. It can also be used as an equivalent of "depth", where "deep colours" and "strong colours" are not the same. NCS uses *saturation* for the relationship between chromaticness and whiteness, a variable that cannot be perceived, where the calculated values have no logical connection to perception and which gives a totally ambiguous value to the black elementary colour. We understand the concept of *NCS-saturation* as a deviation from the NCS's solid foundations in human perception and suggest that it is reconsidered and possibly excluded from the NCS's set of parameters. *NCS-saturation* is one of many attempts to categorise colours as deep or saturated in a meaning that does not coincide with their chroma/ chromaticness. Other similar attempts have been made by, among others, Tryggve Johansson, who created a previous version of the natural colour system, and also within the NCS as a "dual attribute" called deepness. We see the need for further investigations of the perceived colour quality of depth.

1. INTRODUCTION

Ambiguous use of colour terms creates misunderstandings in the colour classroom, among professionals and in customer services. One obvious example is the term *saturation* (German *Sättigung*, French *saturation*, Spanish *saturación*). *Saturation* is a generic word that one nevertheless seldom comes across in casual speech about colour. It is widely used in professional languages of art, design and science, though, and there it has got several parallel definitions. To add to the confusion, the words *chroma*, *chromaticness*, *chromaticity*, *purity* and *colourfulness* are also used, referring to more or less the same thing.¹

2. SATURATION IN ART AND IN EVERYDAY LANGUAGE

The word *saturation* comes from the Latin word *saturare* (*satur* full). In everyday language, *saturation* is not a common colour term, but in art and design parlance, it is widely used, most often referring to the "intensity" or "vividness" of a colour much in the same sense as NCS *chromaticness* and Munsell *chroma*.

¹ Arnkil et al. 2015 includes discussions on several difficulties in colour terminology.

The term *saturation* features in digital colour management in the colour models HSL (Hue, Saturation, Lightness) and HSV or HSB (Hue, Saturation, Value/Brightness). Both HSL and HSV/HSB are cylindrical colour spaces, but with different mappings of the colour variables, resulting in two dramatically different interpretations of *Saturation*.² The term *saturation* is also used in chemistry, referring to the limit where a fluid cannot resolve more of another substance. In painting it can similarly refer to the concentration of the pigment or to the relative contents of chromatic pigment and white. These relative contents affect the chromatic properties of the painted surface differently depending on the pigment. Some pigments, such as yellow ochres, yield their most intense appearance unmixed. For those, *chemical saturation* and *chromaticness* coincide. Other pigments, notably blue ones, such as deep ultramarine, become more chromatic when mixed with a little white. For those, the visual property yielded by maximum chemical saturation could be called *depth*.

3. SATURATION IN COLORIMETRIC LANGUAGE

In the context of a colorimetric colour space the saturation of a colour can be understood as its proximity to its fully chromatic outer limit (Billmeyer & Saltzman 1981 p50) In Hermann von Helmholtz's words, saturation is the proportional mixture of "white" and pure monochromatic light of equal brightness. The same thing is said by Rolf Kuehni, who also clarifies how colorimetric language makes a distinction between *saturation* and *chromaticness*. Varying the brightness of a coloured lamp in total darkness is equivalent to varying its chromaticness. The brighter a red lamp shines, the higher its chromaticness. Kuehni concludes: "Chromaticness is an absolute measure of chromatic content of a colour regardless of its brightness, while saturation is a measure of the chromatic content of colours of equal brightness" (Kuehni 1983, p39f).

4. NCS SATURATION

In the NCS system, developed by the Judd award winning researchers Hård, Sivik and Tonnquist based on the findings of Ewald Hering (Hering 1964), saturation is used in a way that clearly differs from *chromaticness*. In the following text we refer to this as *NCS-saturation*. According to the definition given in the NCS atlas, colours that lie on a straight line from *NCS black* (S) possess equal saturation; thus *NCS-saturation* is defined as the relationship between *chromaticness* and *whiteness*. The illustration in the NCS atlas gives numeric values for each of the shown three lines ($m=0,25$, $m= 0,50$, $m=0,75$) where m refers to the Swedish word *mättnad*, which is used for the same concept as *NCS-saturation* (Svensk Standard 2004). (Fig. 1) The comprehensive scientific presentation of the NCS (Hård et al. 1996 p 188), gives the following equation for *NCS-saturation*:³

$$m = c / (c+w) \quad (m: \text{NCS-saturation, } c: \text{chromaticness, } w: \text{whiteness})$$

Colours that possess equal *NCS-saturation* constitute what is called a "shadow series", a term that we find similarly used in the Ostwald system (Ostwald & Birren 1969). They

² Wikipedia. http://en.wikipedia.org/wiki/HSL_and_HSV. Accessed 15.2.2015.

³ In the comprehensive Swedish presentation of NCS (Hård & Svedmyr 1995), the NCS research team instead defines *mättnad* as $m=c/w$. This means that m can vary between 0 and ∞ , which would give other figures in our discussion about *NCS-saturation* but not alter the principal conclusions.

display the perceived variation of a single coloured surface (or object) in an idealised progression from fully lit to totally shaded, approximating the perceived gradient of colour in a depiction of a round or cylindrical object in directional light.⁴ Thus the concept of *NCS-saturation* does not (and does not claim to) refer to "vividness", but instead denotes a colour property that could rather be interpreted as "depth".

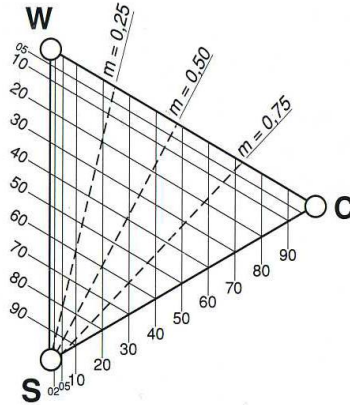


Figure 1: Lines of equal NCS-saturation, from NCS atlas 2004. The lines in the atlas are not precisely drawn – according to the definition the line for $m=0,50$ should go from S to the nuance 0050 and the line for $m=0,75$ from S to the nuance 0075.

Tryggve Johansson, who developed an earlier version of the natural colour system, also uses the concept of saturation (Swedish *mättnad*) in a similar way. He explicitly distinguishes between saturation and *colour strength* (Swedish *färgstyrka*), and uses *saturation* as a synonym for *depth*. He also presents the idea of *oversaturated* (*övermättade*) colours, by which he meant colours that are deeper than the colour that has maximum colour strength. Yellow colours cannot be oversaturated – there is no yellow colour deeper than the strongest one – whereas green, red and especially blue colours can increase in saturation beyond the most chromatic colour (Fig 2) (Johansson 1952 p4-6; Johansson 1965 p22-24)⁵. In pointing out this difference between colours of blue and yellow hue, Johansson implicitly acknowledges an observation that also influences everyday language. Colours with bluish hues are also called blue when they have a great amount of blackness, whereas yellowish colours with the same blackness are called brown or olive (Berlin & Kay 1991, Sivik & Hård 1984).

It is unfortunate that the same word – saturation – has been given these different and partly contradictory meanings. Further analysis of the concept of *NCS-saturation* also shows that it is not perceptually consistent, but rather a mathematical play with the numerical values of abstract parameters. For example, in the case of nearly black colours that can barely be distinguished visually, the *NCS-saturation* varies between the lowest (0) and highest (1) possible value (see table 1).

⁴ It should, however, be noticed that the colour gradient of shading in real spatial contexts depends on the complex situation and cannot be simplified to a straight line in a theoretical model.

⁵ Also discussed in Hård et al. 1996 p181-183.

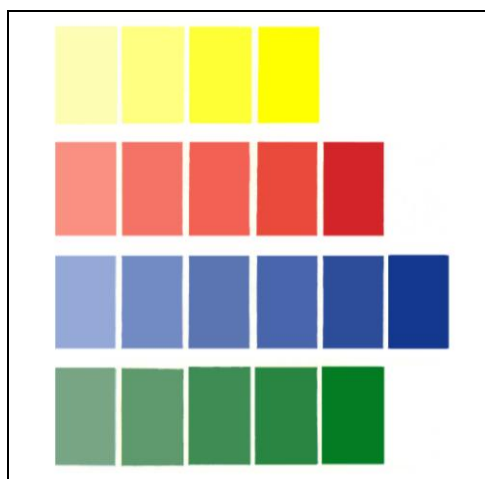


Figure 2: An illustration from Johansson 1965 p22, with Johansson's caption: "Note the difference between colour strength and saturation. The most saturated colours are placed furthest to the right. Those with the highest colour strength are placed as number four from the left." (Our translation and reconstruction of pixelated figure).

Table 1. Calculated NCS-saturation for nuances very close to elementary black.

Nuance	Blackness (s)	Chromaticness (c)	Whiteness (w)	$m = c/(c+w)$	
9900	99	0	1	$0/1 = 0$	On grey scale W-S
9800	98	0	2	$0/2 = 0$	On grey scale W-S
9700	97	0	3	$0/3 = 0$	On grey scale W-S
9901	99	1	0	$1/1 = 1$	On scale S-C
9802	98	2	0	$2/2 = 1$	On scale S-C
9703	97	3	0	$3/3 = 1$	On scale S-C
9801	98	1	1	$1/2 = 0,5$	
9701	97	1	2	$1/3 = 0,33$	
9702	97	2	1	$2/3 = 0,67$	

The table reveals that the grey scale between white and black has *NCS-saturation* = 0. Here *NCS-saturation* coincides with *chromaticness* in a way that creates no conflict with any of the generic meanings of *saturation*. The scale of deep colours, between black and the maximally chromatic colour C, offers much more problems. Here the calculated *NCS-saturation* is maximal. Thus absolute *NCS-saturation* is a quality of all chromatic elementary colours, whereas white has zero saturation. The *NCS-saturation* of elementary black cannot be mathematically calculated, and in the graphical NCS model, black is the end point of all lines showing *NCS-saturation*; this simply makes no sense. Thus, the concept of *NCS-saturation* is misleading in two ways. First, the term *saturation* is not a good choice, as it inevitably leads to thinking about other colour qualities than those referred to by *NCS-saturation*. More serious, however, is the fact that NCS, which is based on colour

perception, introduces a variable that cannot be perceived, where the calculated values have no logical connection to perception and which gives a totally ambiguous value to the black elementary colour. This is not a matter of mere terminology - the concept of *NCS-saturation* would be as illogical and irrelevant to perception whatever it was called.

5. NCS DEEPNESS

In addition to *NCS-saturation*, the comprehensive scientific presentation of NCS includes a concept called *deepness* (Hård et al. 1996 p219). The term is tentatively suggested by the authors who point out that it may be ambiguous. Colours with deepness are characterized by a simultaneous resemblance to both black (S) and the maximal colour (C). Colours around the middle of the scale between S and C have the maximal deepness, according to this definition. Based on phenomenological analysis, the authors hypothesize that the deepness value (dv) can be calculated with the following equation:

$$dv = 40 \cdot s \cdot c / (w^2 + 1000)$$

This means that the nuance 5050 has maximal deepness = 100. Elementary black (S) and the maximal colour (C) both have deepness = 0, as does the white elementary colour. Lines of iso-deepness are shown red in Figure 3, which also shows lines connecting nuances with similar values of the analogically defined concepts greyness and clearness. The NCS authors call the three concepts "dual attributes". They mention that it is also possible to observe a corresponding category of colours that have simultaneous resemblance to two chromatic elementary colours. One example of such "dual attributes" is termed *orangeness*.

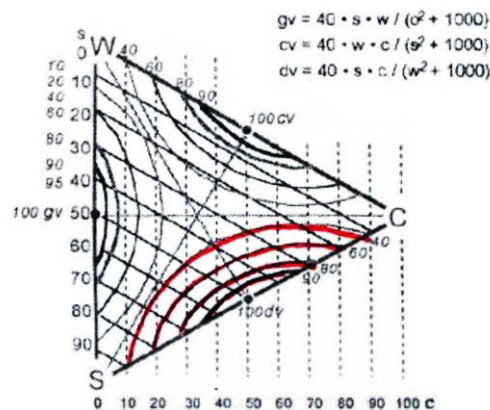


Figure 2: Lines of equal deepness, from Hård et al. 1996 (Marked with red by us).

When looking at the colour triangle one can see some similarity between *NCS-deepness* and Trygve Johansson's definition of *saturation*. For bluish hues, Johansson's maximally saturated (oversaturated) colour would approximately equal the nuance with *NCS-deepness* = 100. There is, however, an important difference: In Johansson's analysis, yellow colours cannot be oversaturated and the most saturated yellow nuance is the maximally chromatic one. In NCS, however, the concept of deepness is used irrespective of hue. Also Paul Green-Armytage (2002) identifies a zone of "deep colours". Starting from the nuance triangle of NCS, he treats all hues in the same way, but his zone of "deep colours" does not fully coincide with *NCS-deepness*.