Learning Colors

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A normal child learns the names for hundreds of objects before learning to name a single color. This is a remarkable fact, well known to many observant parents. Charles Darwin noted this about his own children, and wrote: “I distinctly remember declaring that they were colour-blind.”

But was Darwin right? Were his children, before they could name any colors, really restricted to a bland visual world, devoid of the spice of color? What are the color experiences of a infant, and how do they develop?

The eye of the infant, like the eye of the adult, has four kinds of photoreceptors for catching light. It has rods, which allow vision in low light, and three kinds of cones, which support vision in brighter light. The L cones are most sensitive to longer wavelengths of light, M cones to middle wavelengths, and S cones to shorter wavelengths.

Cones are critical for seeing color. A person who lacks L cones, for instance, is red-green color blind. The gene for L cones is on the X chromosome. Women have two X chromosomes, and therefore two chances to get a correct version of this gene. Men have only one X chromosome, which is why far more men are red-green color blind.

The gene for L cones comes in two normal versions, differing from each other by just one letter—one nucleotide—of their DNA. Among normal men, 38% have one version and 62% the other. The L cones of these two groups of men differ in their peak sensitivity to light by just 4 billionths of a meter. But, in careful tests, the color perceptions of the two groups are found to be consistently different. Thus a change to just one letter of DNA can lead to a change in the conscious perception of color. Moreover, the differences in color perception of these two groups of normal men entails that the answer to the question, “Do we all see colors the same way?” is no.

These color vision tests were performed with adults. The trick, of course, in doing tests with infants is that they cannot talk and cannot follow instructions. But there is a clever way to get reliable data about their color perceptions. Infants move their eyes. They tend to look at things that are new, surprising or interesting. We can show an infant a display containing patches of color and, by measuring where they look, infer which colors they can discriminate, which they prefer, and even how they categorize colors.

Using tests that measure eye movements, it has been found that, at just eight weeks of age, infants can discriminate a large patch of white from a large colored patch of almost any hue. Purer hues are more easily discriminated. This ability continues to improve with age.

At twelve weeks, infants show clear preferences among hues. From most preferred to least, their preferences are as follows: blue, purple, red, blue green, yellow, and green. Careful tests show that these hue preferences are not simply due to other factors such as brightness or saturation.

Thus Darwin was probably not correct when he declared his children were color blind. Even infants can see colors, and they have definite color preferences. But, do infants organize colors into categories? If so, are their color categories similar to those of adults?

Again, clever experiments are needed to answer these questions. In one such experiment, an infant is shown a large square of a uniform color, such as green. Somewhere within the square is a small disk of a different color. Sometimes the disk is just a shade of green that differs from green of the large square, and other times the disk is an entirely different color, say, a blue. The exact colors of the green square, green disk and blue disk are carefully chosen: The difference in color (that is, the difference in wavelengths) between the green disk and green square is the same as the difference in color (wavelengths) between the blue disk and green square.

The experiment measures how long it takes the infant to see the disk. For infants as young as four months, it takes longer to see the green disk against the green background than to see the blue disk. This indicates that at four months of age an infant places blue and green into two different categories, making it harder to find a disk that is in the same color category as the background. Adults tested on the same experiment give results similar to infants.

Infants show color preferences by three months of age and color categorization by four months of age. Perhaps our most sophisticated color capability, however, is color constancy, the ability to see an object as having the same color in different lighting conditions. If you buy a red tomato in a store and take it outside, the tomato still looks red even though the lighting in the store is quite different from the light outdoors. Our color constancy is not perfect. Before a woman buys a dress in a store, she will sometimes take it near a window to make sure she still likes the way its colors look in outdoor light. There can be shifts in the perceived colors when the lighting changes, but our visual mechanisms of color constancy make sure that these shifts are small. This capability is so important that many other species, even the honey bee, have color constancy.

When do children acquire color constancy? An experiment that answered this question showed infants a computer display of colored objects. The computer then simulated either a change in the lighting or a change in the color of the objects.

Infants prefer to look at something new or different. So the question was at what age would their looking preferences indicate that they find the change in object color to be more of a difference than a change in lighting? It turned out that infants at nine weeks of age paid equal attention to changes in lighting and object color, suggesting that they did not yet have color constancy. But at five months of age they paid more attention to changes in object color than to changes in lighting, suggesting that they had acquired color constancy.

So, by age five months an infant has color preferences, color categories and color constancy. A natural next question is whether the color world of an infant depends on its culture. Specifically, does the grouping of colors into categories vary across different cultures? This question has been studied extensively by anthropologists as part of a World Color Survey. Data collected in this Survey from more than 100 nonindustrialized societies tells a remarkable story. The color categories do not vary substantially from one culture to another. Instead colors consistently cluster into categories that go by the English color names of white, black, red, yellow, green, blue, brown, gray, pink, orange and purple.

We must be careful in drawing implications for architecture from this finding. We can expect that the way people perceive and categorize the colors of buildings and architecture elements will be similar across cultures. However, the social, emotional and psychological import of these colors could vary dramatically from culture to culture. For instance, a recent article in this journal by Robert Hillenbrand describes the specific cultural significance of green and other colors in Islamic architecture.

Given that infants can categorize colors by four months of age and have color constancy by five months of age, then why is it that a normal child learns the names for hundreds of objects before learning to name a single color? Many months pass after an infant is competent to categorize colors before it can learn names for its color categories. And in the interim the child learns the names for hundreds of objects, a sophisticated ability that requires expertise at a wide range of categories. Why is this?

The answer lies in the problem a child faces when learning new words. Most often a child learns the meaning of a word by “ostensive definition,” which means that someone points and names. For instance, if little Thomas is looking at a rabbit, and his mother wants to teach him the name, she just points to the rabbit and says “rabbit.”

Remarkably, this is usually enough for Thomas to know what “rabbit” means, and to use “rabbit” correctly in the future. The reason this is remarkable is that Thomas has just solved an incredible problem. When his mother points and says “rabbit” there are literally an infinity of possible things she could be referring to. Perhaps “rabbit” means the ears of the rabbit, or its nose, or its fur, or its white color, or the twitching of its whiskers, or its feet together with the rug it is sitting on.

It takes little imagination to see that this list of possible meanings for "rabbit" is endless.

So how does Thomas get the one right meaning for "rabbit" out of the infinite possibilities? The answer is that Thomas has certain built-in assumptions about what words he will be taught first. One assumption is that his first words will not be about very abstract categories. His mother shares this assumption. She points to the rabbit and says "rabbit"; she does not say "mammal" or "quadriped," even though both words are true of the rabbit. We find it funny to even think about a mother pointing to a rabbit and saying "mammal" because we know intuitively that this is the wrong thing to do. She would be violating a basic rule of the word-learning game.

Thomas also has the built-in assumption that shape, not color, is critical to the meaning of his first words, since it is the shapes of objects rather than their colors that are diagnostic. Rabbits all have a similar shape, but have a variety of colors. Similarly for cars, cows, trucks and most of the objects that Thomas needs to learn first.

So, even though Thomas is already quite competent with colors, he has the built-in assumption during early word learning that colors will not be nearly as important as shapes for word meanings. Only after he has learned quite a few words, indeed hundreds of words, whose meanings depend primarily on shape, is he ready to branch out and begin to learn words related to colors. Thus, Darwin's children were probably not color blind, but were biologically programmed to ignore the colors that they could see during early word learning and to focus instead on shape.

When it does come time to learn the words for colors, once again the child often learns these words by ostensive definition. Someone points, say, to a tomato and says "red" or "the tomato is red." The child already groups colors into perceptual categories before learning the words for colors. So the child can simply apply the new word to a color category it already has. But is it possible that the very process of learning the names for colors could modify these categories? Computer models of word learning for colors demonstrate that, in principle, this learning process could reshape the color categories. But whether this reshaping of color categories in fact happens with real children is an open, and controversial, question.

So far we have discussed the normal development of colors and color words. But there are children who develop unusual perceptions of colors. Some see colors every time they hear a sound, and each specific sound always evokes the same colors. Others see colors when they hear music, or taste foods, or see written letters or numbers. These are all special cases of a condition known as synesthesia, in which a person experiences a mixing of senses that most of us do not. Some synesthesias do not involve color. For instance, there are synesthesias in which every spoken word or phoneme has a taste, and other synesthesias in which every taste has a specific three-dimensional feeling.

But synesthesias involving color are remarkably common. About 1 person in 90 sees colored graphemes, in which each written letter or number evokes its own specific color. The grapheme for 5, for instance, might appear green and the grapheme for 2 might appear red. This specific association between graphemes and colors differs among synesthetics, but the association remains stable for a given person over many years, even over a lifetime.

Sometimes grapheme-color synesthesia can make a task more difficult for the synesthete. For instance, the synesthete might be asked to name the color of the ink in which a number is printed. If the number is 5 and it is printed in red ink, but the synesthete sees a 5 as green, then it takes the synesthete longer to say that the ink is red. Their grapheme-induced colors interfere with their ability to report the actual printed colors of ink.

But sometimes grapheme-color synesthesia can make a task easier for the synesthete. If a synesthete is shown an array of randomly placed 5's, with a single 2 placed at random somewhere among the 5's, the synesthete will be faster than others to detect the 2 among the 5's because, for the synesthete, the 2 is a different color than the 5 and so it is easily seen.

One explanation for grapheme-color synesthesia is based on neuronanatomy and neurophysiology. The area of the brain whose activity is highly correlated with our conscious color experiences is area V4. The area of the brain whose activity is correlated with the recognition of graphemes is right next to area V4. Brain imaging studies indicate that in synesthetes there is much more neuronal cross-talk between these two regions than in non-synesthetes. This extra cross-talk might be the source of the synesthesia.

Thus color, the spice of our visual world, develops early in infancy and uniformly across cultures. Some lucky synesthetes enjoy a bit more spice than the rest of us.