



Data Representation: Millions of Colors

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Lesson Focus

Display devices on cellphones, tablets and computers of all sizes, use bits of information to represent color. By first creating, and then playing a card game, students learn how additive color is represented as binary and hexadecimal numbers. They will also get practice in recognizing and manipulating binary and hexadecimal representations.

Age Levels

Intended for 14 - 17 (US High School grades 9 - 12)
Can be used in upper Middle School (e.g. 8th grade)

Objectives

Introduce students to:

- ✦ number systems used in computing: binary, hexadecimal.
 - ✦ how color is displayed on digital devices.
 - ✦ how and why additive color is represented as a single number.
 - ✦ why there are millions of colors available on mobile devices and computer screens.
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Anticipated Learner Outcomes

Students will demonstrate/explain:

- ✦ how information is stored in binary, and represented in hexadecimal form.
 - ✦ how additive color is represented in binary and hexadecimal.
 - ✦ how to add and subtract hexadecimal numbers.
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Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- ✦ <https://www.mathsisfun.com/binary-digits.html>
 - ✦ https://en.wikipedia.org/wiki/List_of_Crayolacrayoncolors#Standardcolors
 - ✦ <http://www.worqx.com/color/colorsystems.html>
 - ✦ <http://www.mathsisfun.com/hexadecimal-decimal-colors.html>
 - ✦ http://www.rapidtables.com/web/color/RGB_Color.htm
 - ✦ <http://www.rapidtables.com/convert/number/how-binary-to-hex.htm>
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Recommended Reading

- ✦ <http://munsell.com/color-blog/history-of-color-systems/>
 - ✦ https://en.wikipedia.org/wiki/Binary_number
 - ✦ https://en.wikipedia.org/wiki/RGB_color_model
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Optional Writing Activity

- ✦ Write a short report summarizing how additive color is represented in digital computers.

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For Teachers: Teacher Resources

Introduce students to:

- ✦ Number systems used in computing: binary, hexadecimal.
- ✦ How color is displayed on digital devices.
- ✦ How and why additive color is represented as a single number.
- ✦ Why there are millions of colors available on mobile devices and computer screens.

◆ Materials

- ✦ Access to the Internet to learn to do number system conversions, to find the RGB numbers for crayon colors through the Wikipedia Crayola colors page or, by using an online color picker. If you only have one teacher station available, students can take turns using it while others do the paper-based activities. See the Internet Connections section.
- ✦ Unlined white index cards to create a set of playing cards. Heavy stock paper can be cut to a size approximately 4X3 inches. Each student will need 5 cards. Have extras available.
- ✦ A collection of crayons, the larger the number of colors, the better. Markers or colored pencils can be used as an alternative, but will provide a less accurate example. Ideally aim for 5 crayons per students – they don't have to be unique colors, but the broader the range of colors the better. A box of high-end 96 Crayola crayons is less than \$10 on amazon.com. Faber-Castell (German) imported crayons are competitively priced.
- ✦ Paper and pencils to play the game (use scrap paper that has one side clear of copy). Either provide small scraps of paper for submitting answers or use PostIt notes that can be folded in half to hide what is written on them.

◆ Procedure

This activity teaches hexadecimal numbers and RGB color representations in two one-hour sessions. In the first session, students learn about additive color by creating a deck of playing cards that requires matching binary or hexadecimal codes to swatches of color. In the second session students compete against each other to match their color swatch to a hexadecimal or binary representation.

Local school culture will determine the range of colors in your sample. For example, some schools may require each student to have a small packet of colored pencils. In another school an art teacher might have a box of broken crayons collected over the years. Only if you are truly in a situation in which there are no found resources, consider purchasing the [Crayola 64 Crayon box](#) or a larger box of colors. Any brand will do if necessary, however, the activity becomes a bit more complicated. You might also consider borrowing crayons from an elementary aged classroom or school, building the game, then have your students teach the game to the younger children.

Pre-session homework: If appropriate, ask students to bring a variety of old crayons, and challenge them to bring in interesting colors as well as the standard red, yellow, green, and blue. Explain that the wider the variety, the more challenging and competitive the game will be.

This lesson provides hands-on experiences with additive color: the kind of color that occurs in mobile devices and video screens. It also introduces hexadecimal and binary numbers, and how they are used to represent additive color, which is stored in a computer as a binary number.

Students will have to have some understanding of basic arithmetic: adding and subtracting two digit numbers. Converting between hexadecimal and binary representations does not require mastery of decimal arithmetic. Depending on your class, and entirely optional, you may decide to add some instruction on converting between hexadecimal and decimal numbers. A resource for binary to hexadecimal conversion can be found [here](#). Optionally, converting from hexadecimal to decimal can be found [here](#).

Session 1

1. Select one of the videos listed in the section 'Internet Connections' on additive and subtractive color. Review the concepts with your students. Go to the Wikipedia page on Crayola crayon colors and, using the student resource page below, show them how the 'R', 'G', 'B' numbers map to the hexadecimal numbers and how hexadecimal numbers are converted to binary.
2. Distribute twelve index cards and five crayons to each student in your class, along with the Student Resource Sheet and Worksheet 1. If you are short on crayons have students share colors.
3. Following the directions on those pages, each student should create five hexadecimal and five binary index cards to contribute to the deck for your class. Students will need to access the Wikipedia Crayola Crayon website to match their colors. If the crayon color name is still on the wrapper, this should be relatively easy. Students should fill out the information on the worksheet, and check each other's work before transferring the information to the cards. If the color can't be located by name (or if you aren't using Crayola crayons), then color a swatch on an index card and match it by eye against the on-screen options. Explain to your students that they should get as close as possible, and ask a group of students to form a consensus on the match.
4. Leave time at the end to sort all the cards. As students finish the exercise, have them place their hexadecimal cards on the floor starting with the lowest hexadecimal number on the left and the largest on the right. Place redundant cards on top of inserted cards. As students place their cards, start a discussion about what effect is occurring: is this a classic rainbow, or is there a different visual effect? Ask them to posit why the effect is occurring. Designate students to collect statistics on redundant colors and have a discussion about which color(s) predominate. Is the crayon set predominately red, green, blue, or something else? Promote discussion about whether it is easier to 'see' a hexadecimal number than a binary number? Solicit ideas of how you could use the hexadecimal code to study the phenomenon more quantitatively (e.g. can you apply statistics to the color codes). If you have more than two hours, and your students have the expertise, you might consider pursuing this as part of a larger module.
5. Collect the cards into one hexadecimal, and one binary deck, shuffling as you go so that the colors are randomly distributed into each deck. Send your students off with the challenge of how to determine 'how close' one number is to another in each hexadecimal and binary deck. Explain that they will need this skill to win the

game scheduled for the second session. If necessary, suggest there will be prizes (e.g. treats, homework passes etc).

Session 2

1. Divide your class into groups of four.
2. Briefly review how to determine 'how close' one binary number is to another.
3. Distribute three cards to each student in the class. One person in each group collects all the cards to make one group deck. (Yes, mathematically there is one extra card per student, but cards get lost, and not everyone completes the work.)
4. Distribute paper and pencils to each student.
5. Review Worksheet 2, which has the rules of the game.
6. You should determine how much time your students spend on the hexadecimal and binary version of the game. Depending on your class culture, create a timed and consequently, more competitive sport, or keep things calm and slow-paced. If your students are very quick, consider a tournament, where the winners of each group go on to compete with winners from other groups.
7. At most, spend five minutes at the end reviewing the experience. The purpose of the play is to give them practice in reading and writing hexadecimal and binary numbers.

◆ Time Needed

- ✦ 2 sessions, at most, 1 hour each. This can be done in a single two-hour session if your students are typically cooperative during group activities.

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Student Resource:

Additive and Subtractive Color and Hexadecimal Coding

◆ Challenging the Way You Think about Color

Computer display screens, whether on handheld mobile devices or big screen TVs, use *additive color* to produce rich, colorful images. If you've done any coding or web design you may have noticed that video graphics uses an RGB, or red, green, blue color system. This lesson will teach you how a color is represented in a computer as a single, very large number.

◆ Additive Color

RGB produces additive color. A video screen has millions of little points of light called pixels. Each pixel can be lit with a combination of red, green, and blue light. You *add* color and brightness to produce a color. To light those pixels faster than the eye can see, every pixel's information is stored in the computer's memory as a *word* of memory. The code that fills the screen with color runs through that memory grabbing one word (that contains color information) at a time.

◆ Representing Color in Hexadecimal

For historical reasons, *true color* uses 24 bits of computer memory. A bit in binary is either a '0' or '1'. Since most modern computers including smart phones, have 32 to 64 bit words, a color can easily be stored. Each component of additive color uses 1/3 of the 24 bits, or 8 bits each. This is how it works: as illustrated below, the eight bits to the left, called the *high order* bits, hold the bits for 'red'. The next eight bits hold 'green', and the eight bits on the right, called the *low order* bits, hold 'blue'. Using logic, the computer can quickly take this number and convert it into red, green, or blue parts. The original Crayola yellow, created in 1903, is represented in computer memory as:

1111 1011	1101 1000	0111 0000
RED	GREEN	BLUE

◆ Calculating a hexadecimal number

Because human brains have trouble with binary numbers, RGB color is shown to humans in Base 16, which is called hexadecimal. A '#' symbol is often put before a hexadecimal number to distinguish it from a decimal number.

We count to 10 because we (most of us) have 10 digits (fingers) on our two hands. The digits are the number '0' through '9'. When we get to ten, we need another place value. For example:

The number 13 means $10 + 3$, or $1 \times 10 + 3$.

The number 25 means $20 + 5$, or $2 \times 10 + 5$.

The number 325 means $300 + 20 + 5$ or $3 \times 100 + 2 \times 10 + 5$.

Computers store information in *bits* that can be thought of as either 1 or 0. Imagine if you only had two digits with which to count. You still have 0 and 1, but how do you represent 2, 3, 4, 5? Imagine if you had eight fingers on each hand. To count in hexadecimal, we need more than 10 digits. We need a total of 16. Being human, we use the western

alphabet to add digits. Compare the quantities represented in binary, hexadecimal, and decimal:

We can count higher than 9 in decimal. We can count higher than 15 in hexadecimal.

Binary	Hexadecimal	Decimal	Quantity
0000	0	0	
0001	1	1	□
0010	2	2	□□
0011	3	3	□□□
0100	4	4	□□□□
0101	5	5	□□□□□
0110	6	6	□□□□□□
0111	7	7	□□□□□□□
1000	8	8	□□□□□□□□
1001	9	9	□□□□□□□□□
1010	A	10	□□□□□□□□□□
1011	B	11	□□□□□□□□□□□
1100	C	12	□□□□□□□□□□□□
1101	D	13	□□□□□□□□□□□□□
1110	E	14	□□□□□□□□□□□□□□
1111	F	15	□□□□□□□□□□□□□□□

In hexadecimal, when you run out of digits you multiply by 16 rather than 10.

For example, here is Crayola yellow in binary:

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1111 1011  1101 1000  0111 0000
   FB     E8     70
   RED    GREEN  BLUE
    
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This works in hexadecimal, where the color for yellow is #FCE883:

- FB means $F \times 16 + B$.
- E8 means $E \times 16 + 8$.
- 70 means $7 \times 16 + 0$. (This is a very different number from $7 \times 10 + 0$!)

Look carefully at the relationship between the binary and hexadecimal representations.

$$F_{16} = 1111_2, B_{16} = 1011_2, E_{16} = 1110_2$$

Because of the natural relationship between hexadecimal and binary you can *eyeball* the red, green, and blue parts of the color, and, if you know your binary numbers you can quickly convert from hexadecimal to binary. On the other hand, the decimal equivalent is 16409040 which is $251 \times 65536 + 232 \times 255 + 112$. Not exactly easy to remember. This is why graphic artists and web designers prefer to work with hexadecimal numbers.

Finally, notice that digits in a binary number are powers of two, which are easy to remember because you double each time. So for example:

$$1111 = 1 \times 8 + 1 \times 4 + 1 \times 2 + 1 = 15_{10} = F_{16}$$

$$1011 = 1 \times 8 + 0 \times 4 + 1 \times 2 + 1 = 11_{10} = B_{16}$$

In this lesson you will get practice converting between binary and hexadecimal, and be able to recognize color codes.

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Student Worksheet 1: Building a Crayon Color Deck

As a class you are going to build a set of playing cards for a color recognition game. You will need five crayons. Fill in the table. If the crayon still has a wrapper with the name of the color, write down the name. Go to the Wikipedia site for crayon colors: https://en.wikipedia.org/wiki/List_of_Crayola_crayon_colors, and try to find your colors by name. Look in the table for the hexadecimal number and write this down as well. Using the information from the student resource pages, split the color into its red, green, and blue parts, then convert the parts to their binary equivalents. An example is provided using 'Jazzberry Jam,' one of the newest colors that was first produced in 2003.

Don't have a color or a Crayola crayon? Do the best you can to match your crayon color with the available colors.

Color Swatch	Name	Hexadecimal Number	Red	Green	Blue
	Jazzberry Jam	A50B5E	A 5 1010 0101	0 B 0000 1011	5 E 0101 1110

When you've filled in the table, ask a classmate to check your numbers. Ask your teacher for five index cards. Make a swatch of your color on the front of the card, and put the red, green and blue values on the back. Put both the hexadecimal and binary values formatted as shown above.

When you have completed your cards, add them to the sorted collection your teacher is building. In the second section, you will play a game with the cards, which will help you to recognize both hexadecimal and binary numbers.

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Student Worksheet 2: Color Predominance Game

Your teacher will assign you to a group of players and give each of you four cards. Collect your cards into a single deck for the group, and shuffle it. Keep the color swatch side up as you deal the cards out to the players. Don't let the others see the hexadecimal and binary numbers on the back. You will need some paper and a pencil to submit answers. You will need small scraps of paper or PostIt notes to submit your answer.

Choose who goes first: For example: the youngest person, or that person who has the earliest birthday in the year, or whose name starts earliest in the alphabet. Play proceeds in a clockwise direction. The first person gives the first challenge.

Giving a Challenge: Pick a card from your hand, and place card, color side up on the table. Declare whether the others must guess:

- Color predominance (which of red, green, blue) has the highest value.
- What is the hexadecimal value for **one** of the RGB values, for example, you might ask "Guess the hexadecimal value for green."
- What the binary value is for **one** of the RGB values.

Getting a Challenge: Once you're given the challenge, use your scratch paper to write down a guess for the RGB values. Depending on the question, submit your answer by writing it on a scrap of paper, then fold the paper and place it in the center of the table.

Scoring: After everyone has submitted their answer, the challenger reads the answers. If the challenge was to guess which color predominates, the challenger identifies all players who guessed correctly. Each is assigned five points. If the challenge was to guess the number of one color component, the challenger calculates who is closest to the correct answer from below. For example, if the challenge was the amount of green, and the correct answer is 0A, the best answer must be less than 0A. Ties are allowed, and the winners are awarded three points for hexadecimal and four points for binary.

Once the challenger has assigned point values, those challenged may contest the challenger's calculations. If the contested claim proves correct, those who contested the decision each receive 5 additional points, and the challenger subtracts five points.

Played cards are set aside. The game ends when all cards have been played.

Strategy: When you are the challenger, choose your challenge wisely. For example look at the color swatch - if it appears close to a shade of red, green, or blue, it will be easy for the others to guess the predominance. When the RGB values are very close together it may be hard for people to guess.

Two ways to win: The person in your group with the highest score wins the match. The four highest scores with a win, win the class game. Consequently it might be a worthwhile strategy to play to increase everyone's score.

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For Teachers:

Alignment to Curriculum Frameworks

Note: All lesson plans in this series are aligned to the Computer Science Teachers Association K-12 Computer Science Standards, and if applicable also the U.S. Common Core State Standards for Mathematics, the U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics, the International Technology Education Association's Standards for Technological Literacy, the U.S. National Science Education Standards and the U.S. Next Generation Science Standards.

◆ National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ✦ Understandings about science and technology

◆ Next Generation Science Standards & Practices Gr.9-12 (ages 14-18)

Practice 5: Using Mathematics and Computational Thinking

- ✦ Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
- ✦ Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations

◆ Principles and Standards for School Mathematics (all ages)

Problem Solving Standards

- ✦ Solve problems that arise in mathematics and other contexts

Communication Standards

- ✦ Communicate their mathematical thinking coherently and clearly to peers, teachers and others

Representations

- ✦ Use representations to model and interpret physical, social, and mathematical phenomena

◆ Common Core State Practices & Standards for School Mathematics

- ✦ CCSS.MATH.PRACTICE.MP1 Make sense of problems and persevere in solving them.
- ✦ CCSS.MATH.PRACTICE.MP4 Model with mathematics.
- ✦ CCSS.MATH.PRACTICE.MP5 Use appropriate tools strategically.

◆ Standards for Technological Literacy – all ages

Nature of Technology

- ✦ Standard 2: Students will develop an understanding of the core concepts of technology

The Designed World

- ✦ Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies

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◆CSTA K-12 Computer Science Standards Grades 9-12 (ages 14-18)

5.3 Level 3: Applying Concepts and Creating Real-World Solutions (L3)

5.3.A Computer Science in the Modern World (MW)

✦ Computational Thinking (CT)

5. Describe the relationship between binary and hexadecimal representations.

5.3.B Computer Science Concepts and Practices (CPJ)

Computational Thinking (CT)

7. Discuss the interpretation of binary sequences in a variety of forms (e.g., instructions, numbers, text, sound, image).