
REAL Primary Colors PQRST

A 3-dimensional unit on how the eye sees objects and how we use light and paints to create different colors using color addition and color subtraction.

2018 Arizona Science Standards (AzSS)

AzSS: 3.P2U1.1 – Ask questions and investigate the relationship between light, objects, and the human eye.

Next Generation Science Standards (NGSS)

NGSS: 4-PS4-2 – Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.

(<https://www.nextgenscience.org/pe/4-ps4-2-waves-and-their-applications-technologies-information-transfer>)

NGSS: MS-PS4-2 – Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

(<https://www.nextgenscience.org/topic-arrangement/mswaves-and-electromagnetic-radiation>)

Teacher Backgrounder

LED stands for light-emitting diode. Diodes are directional or have a polarity, which means they will only work when current is running through them in the correct direction. If they are connected to a voltage source (a battery) in the opposite direction, they will not light up.

Materials

3 - 20W RGB LED Flood Lights with Remote Control (<http://bit.ly/20WLEDFloodLights>)

- NOTE: 12W RGB LED Flood Lights will also work.

1 large bag of M&Ms or Skittles (colored paper or foam can be substituted for candy)

1 dark room – it does not need to be completely black but as close as possible

1 set of markers/crayons/colored pencils per student – these should include red, green, blue, cyan (turquoise), yellow, magenta (dark pink), orange, brown, and black.

1 – *What Are The Primary Colors?* picture book (request from DaNel Hogan)

- NOTE: Even better to have one copy per two students.

1 set per two students

- 3mm or 5mm Red LED
- 3mm or 5mm Green LED
- 3mm or 5mm Blue LED
- 3 Button Batteries (2032)
- (Optional) flashlight – for writing notes while lights are off
- Tape (clear or masking)

-
- 1 copy per two students – STEMAZing Reflection Box
(<http://bit.ly/STEMAZingReflectionBox>)
 - Either assemble these in advance or provide scissors and tape for students to assemble them. Cut on the dotted lines, fold on the solid lines, and then tape it together at the corners.
 - 1 copy per student – PQRST REAL Primary Colors Journal
 - 1 copy per student – Color Addition – The Primary and Secondary Colors of Light
(<https://stemazing.org/wp-content/uploads/2019/10/RGB-Light-Show-Wkst-Elementary.pdf>)
 - 1 copy per student – Mixing Primary Paint Colors
(<https://stemazing.org/mixing-colors-fingerpainting/>)
 - (Optional) 1 copy per student – Flag and Primary Color Afterimage Optical Illusions
(<https://stemazing.org/flag-and-primary-color-afterimage-optical-illusions/>)
 - 1 – *Ish* picture book by Peter H. Reynolds
 - 1 bottle of paint in each of the primary colors – cyan (sold as turquoise), yellow, and magenta – 16oz side great for one class, get gallon size with pump for multiple classes
(16oz size: <http://bit.ly/16ozPrimaryColorPaint>; Gallon size: <http://bit.ly/GallonPrimaryColorPaint>
AND recommend pump for gallon size: <http://bit.ly/GallonPaintPump>)
 - (Optional) black and white paint to allow for shading and tinting, respectively
 - 1 copy per student – Mixing Primary Paint Colors (KEY also found on some page.)
(<https://stemazing.org/mixing-colors-fingerpainting/>)
 - 1 copy per student – Rainbow-ish
(<https://stemazing.org/paint-rainbow-roy-g-biv/>)
 - 1 per two students – either small paper plates or plastic paint palettes (6 for \$1)
(<https://www.dollartree.com/jot-plastic-paint-palettes/252463>)
 - (Optional) 1 paintbrush per student (finger painting works just fine)
 - (Optional) 3ml graduated pipettes (for measuring paint)
(<http://bit.ly/3mlPipettes>)

Part 1: Color Addition with Lights

Phenomenon – Sorting M&Ms, Skittles, or Colored Paper/Foam in Red Light

Journal Page 1: Before starting with the phenomenon, have students complete the “I think the primary colors are” statement in their PQRST Journals. They should also draw and label a diagram showing how the eye sees a colored object. These will be revisited throughout the unit.

Journal Page 2: Read the “Apple in the Dark” formative assessment probe (adapted from *Vol. 1 Uncovering Student Ideas in Science* by Keeley, Eberle, and Farrin). Have the students select one of the options and describe their thinking. You will revisit this formative assessment probe at the end to see how student understanding has changed.

Prep: Darken a room using blackout curtains and/or other window covers. It needs to be as dark as possible. If you are not able to get the room completely dark, you may want to try the phenomenon before you engage student to ensure it is dark enough for students to be unable to tell different colors apart in the red and blue light.

-
- Turn all the floodlights on to red at full brightness. (NOTE: If you don't have a set of fancy LED floodlights, you can do this phenomenon using red LEDs with button batteries.)
 - Turn the lights off in the room.
 - Hand out M&Ms to the students and instruct them to sort the M&Ms by color.
 - After 5 minute or so, turn on the room lights to see how well they did.
 - Journal Page 3:
 - o have students draw a picture of the piles of sorted objects.
 - o have students complete two "I noticed" sentences. Two things they noticed about the phenomenon.

Questions

Journal Pages 4-5: After students have had time to record their notice statements in their PQRST Journals, let them write I wonder questions. Encourage them to come up with as many as they can and help them with the "I wonder" starter prompts as necessary. If students have questions during the "I notice" time of the phenomenon, let them record questions right away.

Once students have had 5-10 minutes to generate questions, have them share out their questions one at a time and write them on poster paper or your "Wonder Wall". Let them exhaust their ideas and don't discount any questions they have. If you have a particular learning path in mind, you can either pose your own questions or mention an observation, which might get at questions you want students to investigate.

Some questions we expect:

1. I wonder why I can't tell difference between some colors when I was sorting?
2. I wonder how the lights can be changed to different colors?
3. I wonder if this works the same with other colored objects – Skittles, colored marbles, Legos, etc?
4. I wonder how my eye works?
5. I wonder why we used red light to do the sorting?
6. I wonder what would happen if we used a different color of light to do the sorting?
7. I wonder if other animals could sort the colors out in the red light?
8. I wonder how the eyes of other animals work?
9. I wonder what colors other animals can see?
10. I wonder how I see different colors?
11. I wonder why some people can't see some or all of the colors I can see?
12. I wonder how rainbows work?
13. I wonder why sunsets are red?
14. I wonder why the sky is blue?
15. I wonder why black clothes are hotter to wear in the sun than lighter colored clothes?
16. I wonder why some colors make me feel sad or happy or other emotions?

You may want to categorize your questions into groups. The groups might include:

Fact-Check Questions – can easily be looked up in a book or online resource.

- Question 2 can simply be answered by demonstrating to the students how the lights have a remote control.

Scientifically Testable Questions – can be investigated using the Science & Engineering Practices. The constraint on testable questions is the equipment/supplies/measurement devices you have available.

- Question 3 is easily testable given that other colored objects are available for sorting.
- Questions 7, 8, and 9 represents a testable question but one that is beyond the scope of this unit.

Claim, Evidence, Reasoning (CER) Question – is a question which can be explained after the phenomenon has been investigated with a claim about the answer, supported with evidence from the research conducted, and reasoned out based on the model established.

- Questions 1 and 10 will be answered as a CER formative assessment at the end of the unit.
- Question 4 can be answered, in part, using a CER at the end of the unit. It will not include the complexities of rods, cones, and the chemical mechanism of color detection.
- Question 11 will be demonstrated at the “Teach me more” part of the unit.

Beyond Science Questions – are connected to other subject areas and are not testable using science

- Question 17 is a great question but in many ways beyond the realm of science.

Research investigation – using Science & Engineering Practices

Journal Pages 6-7: Given that a form of the following question will be asked - “I wonder what would happen if we used a different color of light to do the sorting?”, have the students make a prediction about what will happen when they attempt to sort the M&Ms in blue colored light. Then, turn all the LED flood lights on to blue and repeat the sorting activity. Have them draw a picture of how they actually sorted the objects in blue light. They should write down two “I noticed” statements and any new “I wonder” questions they have. Add any new questions to the Wonder Wall.

Journal Pages 8-9: If there is time and student interest based on their questions, you can do another round of sorting in a different color of light that they choose. This would have to be green if you are using the LEDs with button batteries as your source of colored light. If you are using the fancy, remote-controlled LED flood lights then there are many colors to choose from. As with above, they should make a prediction about

how the sorting will go first and then draw the actual results once they have done the sorting in the colored light. This should be followed with “I notice” statements and “I wonder” questions. Any new questions should be added to the Wonder Wall. This third sorting activity can be skipped or left for students to explore on their own if there is not enough time.

Journal Pages 10-12: Now it is time for them to investigate color formation using light. Give each group the RGB miniature light show supplies (one red LED, one green LED, one blue LED, three #2032 button batteries, one STEMAZing reflection box, one flashlight (optional but helpful for recording notes in journal as they work), and tape (clear or masking).

- Let them figure out how to get the LEDs to light up. You might ask them what they notice about the length of the leads coming from the LEDs. Ask them how the LED must be connected to the battery in order to get it to light up. NOTE: The negative (short) lead, also called the cathode, must be touching the negative side of the battery. The positive (long) lead, also called the anode, must be touching the positive side of the battery. They might also notice a flat side to the lens/case of the LED, which also indicates the negative cathode.
- Once they have lit up all three LEDs, tell them their task is to investigate how they can make the reflecting box reflect different colors using the three LEDs they have available. They do not have to use all three, all the time. Another way to encourage investigation is to challenge them to see how many different colors they can create. They should be keeping notes on the combination of lights they try and the resulting colors they create in their PQRST Journals.
- While investigating colors, you will want to provide them with the correct vocabulary to describe the colors, including magenta and cyan (sigh-ann). You could pre-teach this before you let them play with the lights. Explain that any color looking turquoise or teal will be called by its proper physics name, cyan, and any color looking pink will be called by its proper physics name, magenta. You could also show them examples of these colors.
- As they discover more and more colors, confirm that they should be able to get at least eight different colors on the screen using the red, green, and blue LEDs. As an added challenge for early finishers, you can ask them how many different colors they can get on the screen all at once. You could torment them a bit by claiming that you can get eight different colors up at the same time!

Science story

Journal Pages 10-12: Either as a class or with groups sharing their findings with each other, compare the data from the investigation. What color did each combination of lights create? How many colors were they able to create? Ask students to draw and label a model of the investigation setup showing how they were able to get different colors using the red, green, and blue LEDs. They should make a claim about colors

they can get with different combinations of LEDs. Have them share their findings with another group and see if the two groups agree. Allow for re-testing if necessary.

Journal Page 13: As a class, decide on the lights required to get all the colors listed. Black = no lights; Red = red light; Blue = blue light, Green = green light, Cyan = green + blue lights; Yellow = red + green lights; Magenta = red + blue lights; White = red + blue + green lights. Discuss any colors they found not listed on this page and have them explain how they created those colors. As an example, they might figure out they can create a purple-ish color by changing the distance of the red and blue light from the reflection box. This is essentially a way of changing the amplitude of the lights.

In the lines next to the colors, have students put "1st" next to the primary colors, which only require a single light to create. Have them put "2nd" next to the secondary colors, which require two primary colors to create.

Journal Page 14: Students should record, again, the primary colors of light – red, green, and blue. They can also color in the arrows to match the colors as a reminder. They should read the information about how secondary colors are created. They can trace the colored light rays represented by the arrows with the correct colors to make this even more visual. Then, they should record the secondary colors of light – cyan, yellow, and magenta. The arrows can again be colored in to match the secondary colors listed.

Virtual research investigation

Journal Page 15: If computers, tablets, and/or smartphones are available, engage students with the PhET Color Vision Simulation. Simply let them navigate to the site and then, play to learn! NOTE: The url for the site is case sensitive. If students can't intuitively figure out the simulation, you can give them hints about turning the lights on using the sliders. After students have had a good amount of time to play, have them complete the "I notice" statements.

<http://bit.ly/PhETcolorVisionRGB>

Teach me more – RGB Light Show Life-sized!

Set up the light show as shown in this video. You will not be rearranging the lights but keeping them in just a single orientation as shown through time 1:20 in the video. Your worksheet looks different because it is the elementary version of the worksheet.

<https://stemazing.org/set-up-for-rgb-color-light-show-video/>

Perform the light show as shown in the video. Note that for elementary, you will only do the first setup as shown through time 4:48 in the video and not rearrange the lights, as shown beyond that in the video.

<https://stemazing.org/rgb-color-light-show-video/>

You will also want to reiterate why color formation with light is called color addition. This is because you start with screen appearing black when none of the lights are on and then you add colored light until we have all the colors our eyes can detect (red, green, and blue). Once all the primary colors of light are on, our eyes then see white. We have added all the colors together.

OPTIONAL: You can also demonstrate what color blindness is with the red, green, and blue lights. The most common form of color blindness is called deuteranomaly which is a reduced sensitivity to green. You could simulate this by dimming the green light. It is more dramatic to simulate deuteranopes where green is completely undetectable. To simulate this form of color blindness, turn off the green light all together to show what the world would look like if your eyes are only sensitive to red and blue light. It helps to have students with a variety of colored clothing in front of the lights.

Protanomaly is a reduced sensitive to red light. Protanopia is the complete lack of sensitivity to red light. This can be simulated by shutting off the red light and leaving the green and blue on.

Tritanomaly is a reduced sensitivity to blue and is very rare. Tritanopia is the complete lack of sensitivity to blue light, and is also very rare. You can simulate this by shutting off the blue light and leaving red and green on.

Revised Model

Journal Page 16: Have students complete the statements about why they noticed what they did in the phenomenon – sorting M&Ms in color. Have them draw and label an updated model for the eye seeing a colored object.

Part 2: Color Subtraction with Paints

Phenomenon – Rainbow-Ish

Journal Page 17: Read students the picture book *Ish* by Peter H. Reynolds. Give them some time to make some “-ish” drawings.

Now, give them cyan, yellow, and magenta paint and the Rainbow-ish handout. Tell them their challenge is to create the simplified colors on the rainbow ROY G BIV. NOTE: These are simplified because the visible spectrum is really made up of an infinite number of colors. They should mix their colors on a separate sheet of paper or a paper plate before transferring it to their Rainbow-ish painting. If they finish their rainbow, then they can paint in the background scene however they would like.

Journal Page 18: After students have had time to complete their Rainbow-ish paintings, they should complete two “I noticed” statements in their PQRST Journals.

Questions

Journal Page 19: After students have had time to record their notice statements in their PQRST Journals, let them write “I wonder” questions. Encourage them to come up with as many as they can and help them with the “I wonder” starter prompts as necessary. If students have questions during the “I notice” time of the phenomenon, let them record questions right away.

Once students have had 5-10 minutes to generate questions, have them share out their questions one at a time and write them on poster paper or your “Wonder Wall”. Let them exhaust their ideas and don’t discount any questions they have. If you have a particular learning path in mind, you can either pose your own questions or mention an observation, which might get at questions you want students to investigate.

Some questions we expect:

1. I wonder why we started with cyan, yellow, and magenta paint?
2. I wonder what the primary colors of paint are?
3. I wonder what color I get if I mix all the colors together?
4. I wonder if I could get black or white with these paints somehow?
5. I wonder why my rainbow didn’t turn out as nice as my friend’s rainbow?
6. I wonder what the secondary colors of paints are?
7. I wonder why paints are different from light?
8. I wonder why we used the secondary colors of light as the first colors of paint?
9. I wonder what happens if you add white paint to a mixture?
10. I wonder what happens when you add black paint to a mixture?
11. I wonder how many different colors I can create starting with cyan, yellow, and magenta?
12. I wonder why we aren’t starting with red, yellow, and blue paints?
13. I wonder if you did start with red, yellow, and blue if you would be able to create as many different colors as you can starting with cyan, yellow, and magenta?

You may want to group the questions into categories as you did in Part 1 of this unit.

Research investigation – using Science & Engineering Practices

Students will be allowed to investigate the question “I wonder how many different colors I can make starting with cyan, yellow, and magenta?” Here is an added twist. Show students a picture of all the paint palette cards at the hardware store. Tell them that the hardware store only carries white paint in cans and not all these colors. If you open up the gallon containers, just white! And yet, you could walk into a hardware store, ask for a particular color, and then buy that colored paint a few minutes later. How is this possible? (They add color to the white paint in recipes to get the colors shown.)

Elementary Hardware Store - Explain to students that they own a paint store and they are attempting to give customers options for paint colors available for them to purchase.

In order to be able to give the customers exactly the color they want, they must be able to record the formula for the color. They must determine a way to systematically measure each color they are using in the color formula so it can be recreated by another group. Restrict color formulas to only using two color combinations at a time. If there are early finishers, then they can investigate combinations of all three colors.

Journal Pages 20-21: Assign some groups magenta and yellow to investigate, some yellow and cyan, and others cyan and magenta. In this way, they only have to investigate one set of color formulas and not all three. Using drops of paint from the pipettes, students should mix different ratios of paint combinations and keep track of their formulas in their PQRST Journals. Students should use C = cyan, Y = yellow, and M = magenta, in their formulas along with a number of drops for each color. For instance, if they mixed three drops of magenta to two drops of yellow, the formula would be $3 \times M + 2 \times Y =$ (their name for color with color sample). They should try to make as many different color formulas as they can with their two paint colors.

For early finishers: They could then pick their favorite color formula, give it to another group, let that group make it according to their specifications, and then compare it to the color they created to see if they match.

Journal Page 22: Explain to students that the primary colors of paint of the three original colors they were given to make their Rainbow-ish. Have them record the primary colors of paint – Cyan, Yellow, and Magenta. They can fill in the bubble with the corresponding paint color. To discover the secondary colors of paint, ask students who has a formula for the best red, green, and blue paint. Have students share the formula for the red, green, and blue paints. You should find that red = magenta + yellow, green = yellow + cyan, and blue = magenta + cyan. They may not be in equal ratios and that is fine. The important part is the two primary colors used. All students should use the formulas given for the bests red, green, and blue to create those colors and put them in their journals.

Science story

Journal Page 23: Now that students have an understanding of the primary and secondary colors of light and paint, they should design a model showing how these two sets of colors are connected to each other. They should attempt to figure out WHY cyan, yellow, and magenta are the primary colors of paint. Students should complete the statement on the bottom of page 23.

Teach me more

Journal Pages 24-25: Students should now read *What are the REAL primary colors?* As they read the book, they should complete the “From the reading” prompts.

How many colors does the visible spectrum, and therefore rainbows, really have?
The visible spectrum has an infinite number of colors.

Because cones in your eye are sensitive to three colors, instead of thinking of white light as all the colors in the spectrum, we can think of it as just being red, green, and blue light added together.

The primary colors of LIGHT are red, green, and blue.

The primary colors of paints (pigments) are cyan, yellow, and magenta.

Cyan paint reflects blue and green light. Cyan paint absorbs red light.

Yellow paint reflects red and green light. Yellow paint absorbs blue light.

Magenta paint reflects blue and red light. Magenta paint absorbs green light.

Journal Page 26: Show this MinutePhysics video called No Pink Light. NOTE: It should be called No MAGENTA Light. <http://bit.ly/MinusGreen> At the end of the video, reiterate that magenta should really be called minus green. Remind students, again, that we can think of white light being composed or made up of just red, green, and blue light based on how the human eye works. Have them read and complete page 26 in their PQRST Journals. Magenta = minus green; Cyan = minus red; Yellow = minus blue

Journal Pages 27-28: Talk through page 27. Have students complete an "I notice" statement on page 28 the pattern they see in the diagram. Can they describe the pattern they see to a friend? Fill in the blanks to the rest of the statements on page 28, referring to the diagram on page 27 if necessary.

If you mix yellow and magenta paint, the yellow absorbs blue light from the white light and the magenta absorbs green light from the white light. The only color left from the original white light is red light. So, when you mix yellow paint with magenta paint, the resulting color is red paint.

If you mix yellow and cyan paint, the yellow absorbs blue light from the white light and the cyan absorbs red light from the white light. The only color left from the original white light is green light. So, when you mix yellow paint with cyan paint, the resulting color is green paint.

If you mix magenta and cyan paint, the magenta absorbs green light from the white light and the cyan absorbs red light from the white light. The only color left from the original white light is blue light. So, when you mix magenta paint with cyan paint, the resulting color is blue paint.

Journal Page 29: Have students complete the two statements.

Evaluation

Journal Pages 30-31: Students should complete the prompts.

Evidence of Learning

- Identification of the REAL primary colors for light and paint.
- Improvement in their model for the eye seeing a red apple which includes white light shining on the red apple, white light consisting of red, green, and blue light, green and blue being absorbed by the apple, red light being reflected to the eye, the red light hitting cones that detect red in the eye and send a signal to the brain which is interpreted as red.
- Improvement in their response and explanation for the Apple in the Dark prompt.

Arizona Science & Engineering Practices Elements Used

- Asking Questions and Defining Problems
 - Identify scientific (testable) and non-scientific (non-testable) questions.
 - Ask questions based on careful observation of phenomena and information.
 - Formulate questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.
- Developing and Using Models
 - Use simple models to describe or support explanations for phenomena...
- Constructing Explanations and Designing Solutions
 - Use evidence (e.g., measurements, observations, patterns) to construct a scientific explanation...
- Obtaining, Evaluating, and Communicating Information
 - Compare and/or combine across complex tests and/or other reliable media to acquire appropriate scientific and/or technical information.
 - Use models to share findings or solutions in oral and/or written presentations, and/or extended discussions.

Arizona Crosscutting Concepts Elements Used

- Patterns: Patterns of change can be used to make predictions.
- Cause and Effect: Cause and effect relationships are routinely identified, tested, and used to explain change.
- Systems and System Models: A system can be described in terms of its components and their interactions.