Light and Color

Laboratory for Primary Level Students

Teacher Manual

WS2

WOMEN SUPPORTING
WOMEN IN THE SCIENCES

Mission Statement

This laboratory will teach light and color concepts to a target audience of elementary/primary-aged students (ages ~6-12) through experiments related to how light travels and how light is absorbed, reflected, and transmitted.

Contents

1. Introduction to WS2 Laboratories

1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to 5000 primary and secondary school students, predominantly in eastern Africa. The lab kits are intended to utilize local resources and include topics that are especially relevant to young girls in order to spur their interest in STEM subjects. The international teams, which designed the content found in these laboratory manuals, worked with WS2 Partners in eastern Africa in order to successfully deliver and teach the science lab kits to their local communities through 2022. WS2 gratefully acknowledges the hard work of the teams in the creation of this lab kit content. For more information about WS2, please visit our website at ws2global.org.

WS2 is sponsored by the APS Innovation Fund, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 Partners receiving lab kits are representatives from Makerere University (Uganda), Masinde Muliro University of Science and Technology (Kenya), Mbeya University of Science and Technology (Tanzania), Mkwawa University College of Education (Tanzania), Nelson Mandela African Institution for Science and Technology (Tanzania), University of Dar es Salaam (Tanzania), University of Dodoma (Tanzania), and University of Rwanda (Rwanda). The APS, Materials World Modules, SciBridge, and Projekt Inspire have provided valuable input on WS2 lab kit design. WS2 especially thanks WS2 Partner representatives (John Bakayana, Pendo Bigambo, Daudi Mazengo, Lawrence Robert Msalilwa, Celine Omondi, Marcellin Rutegwa), Tom Coon and students of Haile-Manas Academy (Debre Birhan, Ethiopia), and Carla Johnston and students of Frank Bergman Elementary School (Manhattan, KS, USA) for piloting the lab kits with small focus groups in late 2021. WS2 also tremendously thanks the virtual lab kit design team that created the content for this lab manual.

1.2. Using this Guide

This manual is to be used by the teacher of the laboratory, and it is similar in content to the student manual but contains additional material, namely: Overview, Fundamental Physics and Materials Science Concepts Covered, Practical Skills, Background on Main Topics, Summary of Experiments, Results, Teacher Pre-Lab, Troubleshooting. These additional sections are intended to provide the teacher with the background and foundation critical for successfully implementing this laboratory kit in the classroom. It is recommended that the teachers of this laboratory go through the guide from beginning to end to familiarize themselves with the laboratory content prior to teaching the laboratory to students. Questions about the laboratory content can be directed at any time to ws2global.org@gmail.com, using the subject line "Question about Lab Kit Content".

<u>IMPORTANT NOTES:</u>

- This laboratory is intended for use with primary-level students (ages ~6-12), but depending on the specific students' educational background, the content may need to be modified by the teacher to be made simpler or more complex. The teacher is encouraged to also cover the laboratory content at the pace that works best for the students; some younger students may need more time and attention from the teacher and/or facilitator to go through the questions and experiments, while older students may be more independent and require less attention from the teacher and/or facilitator. Thus, the content covered, depth of coverage, and pacing are left to the teacher's and/or facilitator's discretion.
- The content in this lab manual may not fit into the specific curriculum of the school in which it is being taught. It is up to the facilitator(s) and teacher(s) whether they would like to introduce new content or skip certain sections that are not applicable to their classrooms.
- In certain areas, modifications to the supply list may need to be made depending on the availability of the supplies in the specific area in which the lab is being taught. We have attempted to list some alternatives in the supply list, but we understand this list of alternatives is not exhaustive.
- In the experiments, the students are split into groups of three to four. If supplies allow, students may instead be split into groups of two.

1.3. Key Vocabulary

- Light: A type of energy that helps us see (the Sun is an important source of light!); this type of energy can travel in waves ("light waves")
- Transmission: When light travels through an object
- Reflection: When light bounces off an object
- Light Absorption: When light is taken in by objects and converted into energy
- Transparent: See-through; describes an object that lets light pass through so that objects behind it can be distinctly seen
- Opaque: Not see-through; not transparent; describes an object that does not let light pass through so that objects behind it cannot be distinctly seen

1.4. Key Questions

- What happens when light is blocked? What are some examples of light being blocked in your life? How do you change this so that light can instead pass through?
    - Answer: When light is blocked, light waves can no longer move from one point to another point. Depending on the object in the path of light, light will be absorbed, transmitted, or reflected. Light can be blocked by many things including walls, paper, hands, hats, trees, and clouds. You change this by either choosing a different material in the path of the light (for example: like using a window instead of a wall so that light can pass through) or removing the object stopping the light from passing through.
- Why are many plants and leaves green? Why are some flowers red, yellow or orange?
    - Answer: Plants are green because they reflect green-colored light and absorb red-colored light most efficiently. The absorbed, red-colored light is used for photosynthesis in the plant and the green-colored light is not used, so we can visibly see the colors of light not being used in the plant by its physical appearance. In other plants, like flowers, colors can come from the reflection of light, like the green from plant leaves, or from pigments. Pigments are colored materials that are found in many

things like plants, flowers, clothes, and paints. Changing the pigment means changing the color!

1.5. Purpose

In this lab, students will learn what light is and how it travels. Light is important because it helps us to see and is responsible for the different colors we see. Light, mostly from the Sun, is also the main source of energy for most living things.

1.6. Overview

Through this laboratory, elementary/primary-aged students (ages ~6-12 years) are going to be taught light and color concepts through experiments related to how light travels and how light is absorbed, reflected, and transmitted.

1.7. Fundamental Physics and Materials Science Concepts Covered

This laboratory introduces the topics of Light and Color, relevant to Physics (e.g., energy, waves) and Biology (e.g., photosynthesis), to elementary/primary-aged students. Specifically, the labs encourage students to think about light movement, transparency/opacity of materials and objects to light, and absorption/reflection of color.

1.8. Practical Skills

- Students will be exposed to the color wheel.
- Students will understand how different objects appear different colors.
- Students will connect light and color concepts to everyday experiences at school and home.

2. Background on Main Topics

2.1. Light and Color

Humans have always needed light. Our ancestors, who survived by foraging, hunting, and farming for their food, scheduled their days around the Sun. Back then, without light from the Sun, they could not see anything! Our dependence on light has led to the discovery of light sources other than the Sun. This began when we created light by making fire from wood, oil, and gas. As time went on, other light sources such as incandescent light bulbs, neon lights, lasers, and more complicated lights, like light-emitting diodes, were invented. With the invention of artificial (this means made by humans) light sources, humans could extend our days into the night. Besides humans needing light to see, plants need light because light is their energy source for something called photosynthesis, which is the way plants produce their own energy or "food". Plants are very important, because they also produce the oxygen that we need to breathe. Humans and plants live in a shared world that depends on both living and nonliving things. The shared world is also called an ecosystem.

Light is essential for our lives, so it is important for us to understand the basics of how we see light and color! Light is a type of energy that is made up of different lengths of light waves. These light waves travel through space to get to us. Certain light waves are called visible light waves and humans can see them with their eyes. Colors, like red, orange, and green, that we see come from visible light.

When visible light waves hit an object, they are either transmitted through, absorbed by, or reflected off the object. Transmission means that light can travel through an object, like in Figure 1 (right). Reflection means that light bounces off an object and sometimes hits our eye, helping us to see an object and its color like in Figure 1 (left). Light absorption means light is taken in by objects and is converted into energy like in Figure 1 (middle). Depending on which of these happen when light hits an object will change what we see, including colors we see! You can see examples of these processes in the picture below. If an object allows light to pass through it easily so that you can see through it, this object is transparent. If an object cannot be seen through, this object is opaque, and light cannot easily pass through it.

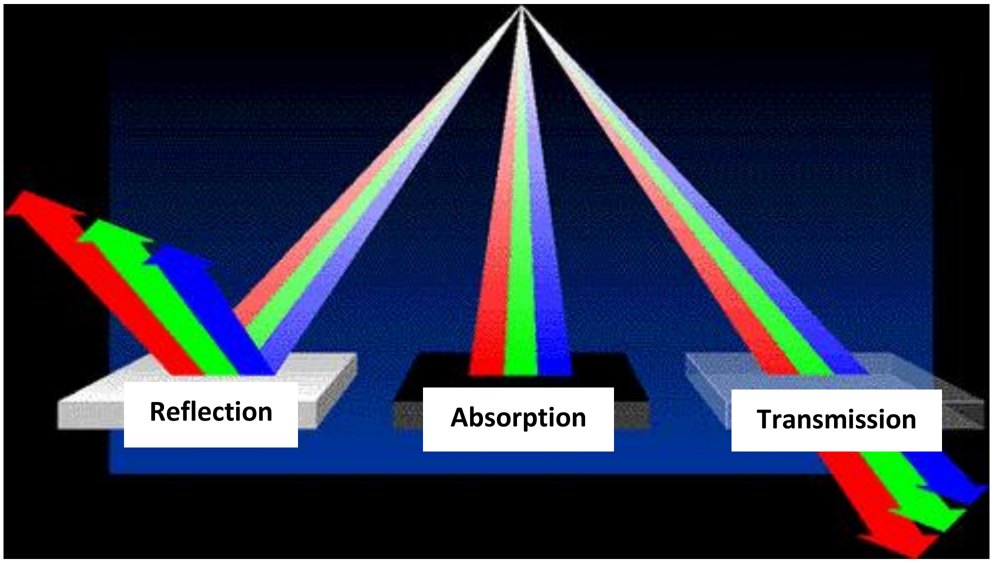


Figure 1. Examples of reflection (left), absorption (middle), and transmission (right) of light waves. The direction of the light is represented by the blue, green, and red arrows. Source: maggiesscienceconnection.weebly.com

2.2. Sources

Mason, Betsy. A Brief History of Light. Wired, https://www.wired.com/2008/12/gallery-lights/.

Reflection, Absorption & Transmission. Maggie's Science Connection, https://maggiesscienceconnection.weebly.com/reflection-absorption--transmission.html.

3. Summary of Experiments

This lab consists of three experiments and one design challenge to understand the concepts of light and color. In the first experiment, dealing with light propagation, students will investigate how light moves from one point to another in the form of a wave. Students will see that light travels in a straight line. However, when light is blocked by an object (in this case, a bent straw), the light cannot travel through to your eyes. The second experiment looks at the propagation of light through an opaque material (cardboard) versus a transparent medium (clear plastic). This will demonstrate that light can travel through transparent objects but not opaque objects. The third experiment will address the fact that light is not colorless, but instead made of an array of colors (the rainbow). The color we see is what gets reflected while the rest gets absorbed by the object. Red, blue, yellow, black, and white clothes will be used for students to identify the color that is being absorbed and reflected. The final design challenge allows students to use the concepts they have learned about light and color to design their future home with transparent and opaque materials.

3.1. Supplies List

- Light sources (sunlight, fluorescent bulbs, candles, etc.)
- Straws or hollow tubes of any kind or color
- Thread or string
- Cardboard
- Clear plastic (binder sheet or other piece of plastic)
- Pencil
- Scissors
- Water
- Spray bottle
- Fabric of various colors (T-shirts or other fabric): white, black, blue, red, yellow
- Ruler (optional)
- Flashlight (optional)

3.2. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- Students should never look directly at the Sun. This can permanently damage their eyes. If you are using the Sun as a light source, have the students look at a sunny spot on the ground or at the horizon away from the direction of the Sun.
- The students need to be careful when working with candles. Since they are a fire hazard, the table should be cleared of all objects when performing the experiment.

3.3. Teacher Pre-Lab

To avoid injuries, teachers should assist and/or supervise the students when using scissors to cut holes in the plastic and cardboard sheets for Part II.

Teachers may print the following to save time from making a data table.

- Appendix B – Color of Fabric and Temperature Data Table for Part III

4. Experiments

4.1. Part I. Propagation of Light

4.1.1. *Pre-Experiment Questions*

1. What are some examples of light sources?
   a. Answer: Sunlight, flashlights, lamps, candles, fire, lightning.
2. How does light travel?
   a. Answer: Light travels from one point to another in the form of waves.
3. What parts of life need light? How can you tell those things need light?
   a. Answer: Can be a variety of answers: plants/flowers need light because without light the leaves would shrivel and die; vegetables and fruit need light to grow large and strong with nutrients; people use sunlight to make Vitamin D in their bodies and to grow food to eat.

4.1.2. *Materials*

- Straws or tubes
- Source of light (indirect sunlight, lamp)

4.1.3. *Procedure*

1. Take one straw or tube and hold it up to your eye. Do not point the straw directly at the Sun!! This will damage your eyes.

2. Look through the straw at objects around you.
3. Record with words or drawings what you see.
4. Bend the straw once.
5. Repeat steps 2. and 3.
6. Bend the straw once more so that the straw is now bent twice.
7. Repeat steps 2. and 3.

4.1.4. *Results*

What I see through the straw	What I see through the straw bent once	What I see through the straw bent twice

4.1.5. *Post-Experiment Questions*

1. When you first looked through the unbent straw, could you see objects and light? What does this mean?
    a. Answer: When the straw is straight the light can travel through the straw. This means you can see light and objects through the straw.
2. When you bent the straw once, could you see objects and light? What about when you bent the straw twice? Compare the objects and light you saw before and after bending the straw.

    a. Answer: When the straw is bent the light cannot travel through the straw as easily. The light is blocked by the straw and reflected away from your eyes.
3. What does this experiment show you about how light travels?
    a. Answer: Light travels in a straight line. It was blocked by the straw when it was bent.
4. Can you guess how can plants adapt to low light conditions?
    a. Answer: Can be a variety of answers: plants can adapt to different light conditions by finding ways to move their leaves with the direction of the Sun; open up their leaves more; tilt their stem and leaves in direction of sunlight.
5. Extension: Plants are amazing! Have you ever noticed the behavior of clovers? They actually "open up" so more of their leaves can reach the light. Other plants actually can tilt and bend towards the light to get more sunlight. This behavior is called tropism. Tropism is a change in the direction of a plant's growth in response to something outside the plant, like sunlight or water. Phototropism is when the plant growth changes direction due to light, usually from the Sun. There is a picture of phototropism in a houseplant (called the false shamrock) below in Figure 2! Look at how the leaves change between day and night. Can you guess how the false shamrock's leaves would change if the day was sunny? What if the day was rainy and cloudy?
    a. Answer: The leaves would be more open to the sunlight on a sunny day and would be less open on a cloudy day, much like how the leaves look at night.

Figure 2. The false shamrock during the day (left) and at night (right). See how the shape of the leaves change?

4.2. Part IIa. Opaque Materials

4.2.1. *Materials*

- 3 pieces of cardboard (or thick paper or non-transparent plastic that can be cut)
- Pencil
- Thread or string
- Source of light (candle or lamp)
- Scissors
- Ruler (optional)
- Flashlight (optional)

4.2.2. *Procedure (work in groups of 3-4)*

1. If not already done, cut your cardboard into three pieces that are the same size.
2. Using a piece of string, measure the length about halfway up the height of the cardboard pieces. This means that the same amount of cardboard is above the length of the string as the distance that the string covers.
3. Next, either make a mark on the string at this distance or cut the string using scissors. You will use this length of string to align the holes you will cut in the cardboard.
4. Use your pencil and string to mark where you will cut a hole on each cardboard piece.
5. Carefully use your scissors to cut 1 small hole in each of the 3 cardboard pieces. The holes should be large enough to see through (~2 cm wide).
6. Arrange the three pieces of cardboard so that all the holes at the center are in a straight line. This can be done by using a piece of string that you may pass straight through the holes of the cardboard pieces. Work with your team to hold up the string or pieces of cardboard.
7. Place a light (candle, lamp, or flashlight) at one end of the set up as shown in the diagram.
8. Look through the holes in the cardboard at the opposite end of the light.
9. Now, move the cardboard pieces slightly to prevent the person looking through the holes from seeing the light.

10. Take turns so that each team member gets to view the light through the cardboard pieces (steps 6-9).

Experimental set-up for Part II is shown in Appendix A.

4.2.3. *Post-Experiment Questions*

1. What do you see when the holes in the cardboard are aligned?
    a. Answer: When the holes are aligned, you can see light through the holes that travels into your eyes.
2. What do you need to do to prevent light from traveling though the holes? How many ways can you set up the cardboard pieces to achieve this?
    a. Answer: To block the light from traveling through, you need to move at least one of the holes out of alignment. There are many ways to do this by moving the first, second, or third cardboard piece to the side, up, or down. Anything that misaligns the holes will work!
3. When we can't see light through objects, we call them opaque. What are some uses of opaque materials? What do you use opaque materials for in your life?
    a. Answer: Opaque materials are good for many things including privacy and storing foods that go bad in the sunlight. We use opaque materials for clothing, homes, paper, and (most) food cans!

4.3. Part IIb. Transparent Materials

4.3.1. *Materials*

- 3 pieces of clear plastic (binder sheets)
- Pencil
- Thread
- Source of light (flashlight, candle, lamp)

4.3.2. *Procedure (work in groups of 3-4)*

1. If not already done, cut your plastic into three pieces that are the same size.
2. Using a piece of string, measure the length about halfway up the height of the plastic sheets. This means that the same amount of plastic sheet is above the length of the string as the distance that the string covers.
3. Next, either make a mark on the string at this distance or cut the string using scissors. You will use this length of string to align the holes you will cut in the sheets.
4. Use your pencil and string to mark where you will cut a hole on each sheet.
5. Carefully use your scissors to cut 1 small hole in each of the 3 plastic sheets. The holes should be large enough to see through (~1-2 cm wide).
6. Arrange the three plastic sheets so that all the holes at the center are in a straight line. This can be done by using a piece of string that you may pass straight through the holes of the sheets. Work with your team to hold up the string or plastic sheets.
7. Place a light (candle, lamp, or flashlight) at one end of the three sheets.
8. Look through the holes in the sheets at the opposite end of the light.
9. Now, move the plastic pieces slightly to prevent the person looking through the holes from seeing the light.
10. Take turns so that each team member gets to view the light through the plastic pieces (steps 6-9).

4.3.3. *Post-Experiment Questions*

1. What do you see when the holes in the plastic sheets are aligned?
    a. Answer: You can see light through the holes of the sheets when they are aligned.
2. What do you see when you misalign the holes in the sheets?
    a. Answer: You see light regardless of whether the holes are aligned.
3. What is the difference between this experiment with cardboard and plastic sheets?
    a. Answer: In the cardboard experiment, the holes had to be aligned to see light. In this experiment, the light shines through the material any way the holes are aligned.

4. When we can see light through a material, we call it transparent. What is the advantage of transparent materials?
    a. Answer: Transparent materials are better for seeing objects and light on the other side.
5. What are some examples of what you would use transparent materials for?
    a. Answer: Transparent materials are better for windows, glasses, or plastics where we want to see the objects inside. Students can come up with a variety of answers.

4.4. Part IIIa. Rainbow in a Bottle

4.4.1. *Pre-Demonstration Questions*

1. Does light have color?
    a. Answer: Yes! It is made of the colors of the rainbow, there are 7 main colors (red, orange, yellow, green, blue, indigo, violet).
2. When have you seen the colors of light?
    a. Answer: In a rainbow we see the seven colors of light separated. We can see the colors of light in many other everyday situations: flowers, the sky, plants. Answer will vary.

4.4.2. *Materials*

- Sunlight
- Spray bottle
- Water

4.4.3. *Procedure (demonstration by teacher)*

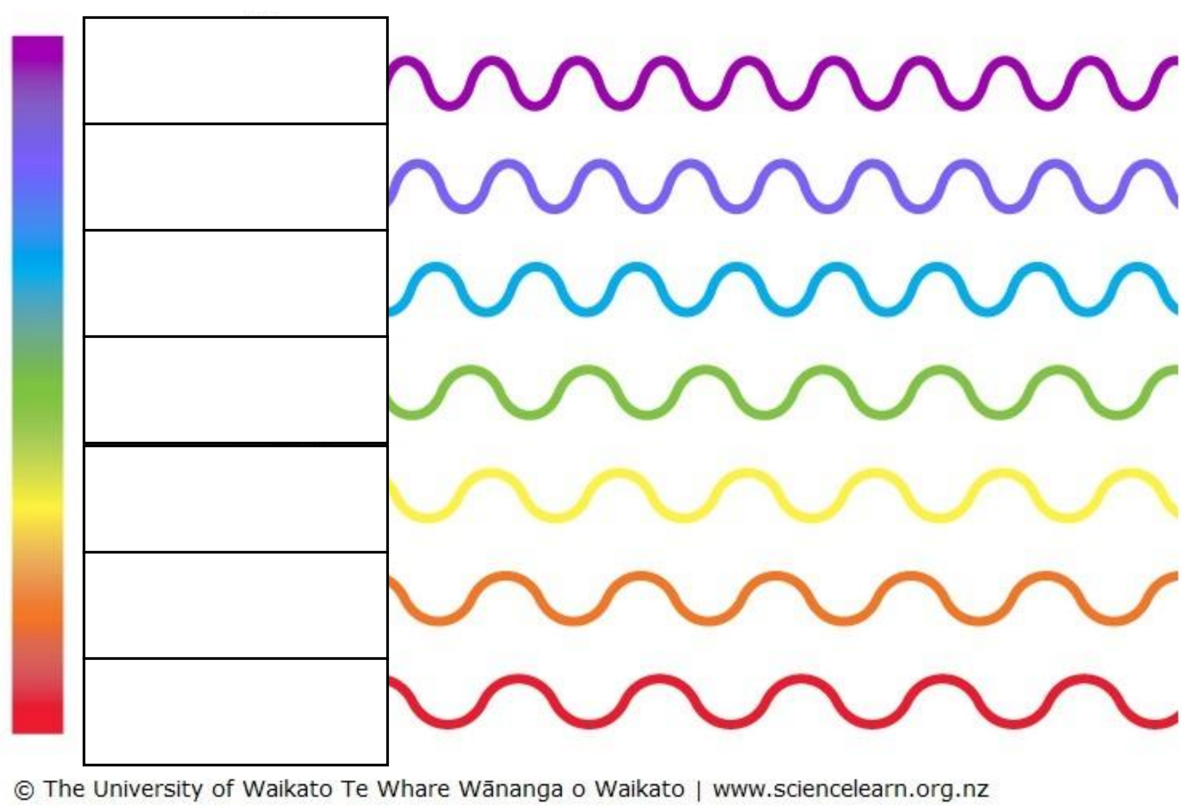
1. Fill a spray bottle with water.
2. Find a space outside where you are in direct sunlight.
3. Spray water a few times in the sunlight and watch the sprayed water.

4.4.4. *Post-Demonstration Questions*

1. When water is sprayed in the sunlight, what do you see?

   a. Answer: When viewed at a certain angle, you can see a rainbow of colors in the sprayed water.
2. If you see colors, how many colors do you see?
   a. Answer: You see 7 colors: Red, Orange, Yellow, Green, Blue, Indigo and Violet.
3. What are some other examples of when you see a rainbow of light?
   a. Answer: After it rains, and it is sunny. When light shines into a puddle on the ground. There can be many answers.
4. Extension: The colors of light that you identified in your rainbow are all in visible light from the Sun. These seven colors are sometimes remembered with the letters ROY G BIV, and these colors are often placed on lines or in a circle, sometimes called a color wheel. Now that you know the seven colors in the rainbow, try labelling them on the color wheel and color line below (in the white rectangles).

Source: Pinterest



Source: sciencelearn.org.nz

Remember that light travels in waves? The so-called length of the wave of visible light is specific to the color. See how the red wave looks more stretched out than the purple wave? The color red is a type of light that has a longer wave than purple. If you combine all of the colors on this color line, you end up with white light. Sunlight contains all of the colors of the rainbow!

4.5. Part IIIb. Light Absorption

4.5.1. *Materials*

- Black fabric (or clothes)
- While fabric (or clothes)
- Other fabric colors (optional)

4.5.2. *Procedure (work in groups of 3-4)*

1. Gather black, white, and other colored fabrics. Write the colors of each fabric in the data table (Appendix B).
2. Note the temperature of each fabric (hot, cold, warm) by how it feels to your touch in the data table.
3. Make your predictions in the data table for the fabric that will heat up the fastest in the sunlight and the slowest in the sunlight. This guess as to what you think will happen is called your hypothesis!
4. Lay the fabrics out in the sunlight.
5. After ~30 minutes check the temperature of the fabric by touching each with your hands. Record your results in the data table.

4.5.3. *Post-Experiment Questions*

1. Which fabric color became the hottest?
    a. Answer: The black fabric becomes the hottest.
2. Why do you think some fabrics became hotter than others?
    a. Answer: White fabric reflects the light, keeping it cooler. Black fabric absorbs the light, making it heat up more quickly. The darker the color of the fabric, the more light it will absorb and the more it will heat up.

3. Do you notice this effect in your everyday life? What are some examples?
    a. Answer: A paved street that is black will get very hot in the Sun. Dark clothes may dry faster on a clothesline than lighter clothes. Black colored shoes can become hotter on your feet than lighter colored shoes in the Sun. Black roofs may absorb sunlight to keep your house warm while light colored roofs keep your house cool.
4. How could you use this information to decide what to wear on a hot and sunny day?
    a. Answer: On a hot sunny day, you may want to wear light colored clothes to stay cool because they reflect the sunlight!
5. Pick a colored fabric (not black or white). What color is being absorbed and what color is being reflected? Remember what your eye sees is the color that is bouncing off of the fabric.
    a. Answer: The color you can see is being reflected, the other colors are absorbed.
6. Extension: Can you guess why the sky is blue?
    a. Answer: Our atmosphere has lots of stuff floating around in it – mainly gasses and other particles. The light waves from the Sun bounce off of these particles. We see blue here on Earth because blue light is scattered more than other colors!

5. Design Challenge

The Challenge: It is time to design your future home! Your task now is to pick out the materials you will use for your home. Think about all you have learned about light and color, as well as reflection and absorption, when you answer the following questions. This challenge can either be done by simply thinking about your future home and drawing it or, if you have the supplies nearby, you could actually build a mini model of your future home.

5.1 Design Questions

1. If you were going to build a house today, what materials would you use for your windows?

    a. Answer: Glass or a transparent material so light can be transmitted into the house.

2. Where do you want your windows to be to let in light throughout the day? Will these windows make it hot inside? Will they make it cold? What could you do to help keep the inside of your house comfortable all year?
    a. Answer: Too many windows could make your house too hot or too cold depending on the climate and the time of year. To help with this, you could put one window in each room or make your windows have extra glass to keep the cold out (we think of this as insulation). You could also make the windows long and skinny to let in lots of light without letting in too much heat or cold. Think about the direction your house faces as well. The Sun rises in the east and sets in the west, so if you're a morning person maybe you want more windows facing the east. Students can be creative!
3. What materials would you use for your walls? Why do you want to use these materials?
    a. Answer: You can use wood, clay, stone, concrete, metal, or anything opaque. You want materials that are strong to hold up the house but that are also opaque so that light cannot get through. This is for privacy and to keep strangers from seeing inside.
4. What materials would you use for the roof?
    a. Answer: For a roof material, you want to use something that will not let in the rain or wind like metal, thatch (sticks, grass, and mud) stone, or tar. Sometimes we include windows in the roof to let sunlight in during the day.
5. Now, there is no electricity in your house and your only source of light is the Sun. But, you have a magic window that can move in any direction throughout the day! Where would you move your window in the house throughout the day? Sketch this idea out.
    a. Answer: Follow the Sun at different angles. For example, at 12 pm, you would want a window in the roof to get maximum sunlight. Students can sketch their answer to this question. An example sketch is shown in Appendix C.

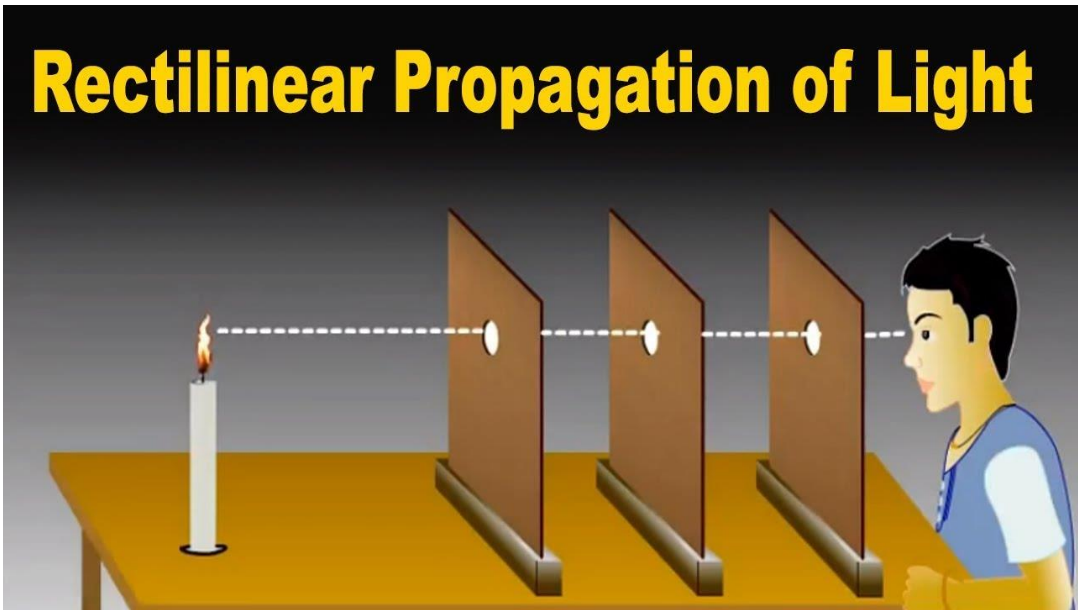
5.2 Design Sketch or Prototype

Try out your design by sketching it on paper and coloring it in with markers, pens, pencils, and crayons. You can also make a small model of your future home using pieces of cardboard and plastic as opaque and transparent materials. Be creative!

<u>My future home:</u>

6. Appendices

6.1 Appendix A – Experimental Set-up for Part II



6.2 Appendix B – Color of Fabric and Temperature Data Table for Part III

Material Color	Starting temperature (cold, cool, warm, or hot)	Prediction of how fast each material will heat (fast, medium, or slow)	Ending temperature (cold, cool, warm, hot, super-hot!)
#1			
#2			
#3			
#4			
#5			

6.3 Appendix C – Sketch of Design Result