C4 Sense of sight

Subexperiment C4.1 Perception of colors
Subexperiment C4.2 Our field of vision
Subexperiment C4.3 You need light to see
Subexperiment C4.4 Where do the colors of the rainbow come from?

1 Main question

The following questions underlie the subexperiments and guide the activities:

- What information do various colors transport?
- What emotions and properties do people associate with different colors?
- How does perception change when you look through colored film?
- How large is your own field of vision?
- How do the fields of vision of your left and right eyes differ?
- What is the advantage of a binocular field of vision?
- In what area of the field of vision can we see colors?
- What do we see in the dark?
- How do we perceive colors in the dark?
- How can you allow your eyes to get used to the dark?
- What is “visible light”?
- Where do the colors of the rainbow come from?

2 Background

2.1 Relevance to the curriculum

Investigating natural phenomena of one’s own body will kindle the children’s interest in scientific thinking. When the children investigate the thresholds of their own field of vision, cross-references to technical instrumentation can be established. For example, talk about eye exams. Children who wear glasses or contact lenses can certainly help out a bit since they are already familiar with medical examination equipment.
The students will become familiar with natural phenomena and processes, for example, by observing how their perception of colors changes when they look through colored films. This focus on their own bodies and their own perception also contributes to the students’ personality development.

Topics and terms

Electromagnetic radiation, colors, color perception, field of vision, light, colors of light, rainbow, red-green color blindness, visual defect, visual impairment, sense of sight, visible light, spectral colors, perception

2.2 Skills

The students will ...

- become familiar with the topic of vision and the associated sense of sight in humans.
- recognize individual differences in the perception of colors and the size of the field of vision.
- recognize the importance of light for people to see colors.
- be able to make comparisons with the animal world.
- gain initial insight into the spectral colors of visible light.

3 Additional information on the experiment

You will find additional media for preparing or for further study of this experiment on the media portal of the Siemens Stiftung:
https://medienportal.siemens-stiftung.org

4 Conducting the experiments

Notes:

- The required apparatus and materials that are not supplied as well as those that are supplied in the kit are designed for experimentation by **one** group of a maximum of **five** students. In total, the material in the kit is sufficient for **ten** groups of students.
- We recommend that you have the students set up all subexperiments and additional experiments at the same time and then have the groups move from station to station. This allows all students to conduct all experiments next to each other in one room. The sequence of the individual stations can vary for the groups; a specific sequence doesn't have to be followed. For example, in the "You need light to see" subexperiment, the students only need to prepare one table with a blanket. If you want to incorporate an additional station, such as for internal differentiation for the students with extra time, the topic of optical illusions is a good option.

4.1 Subexperiment C4.1 Perception of colors

4.1.1 Apparatus and materials

Supplied

- 10 color pictures of various objects and symbols
  (see the guide book binder: 5 laminated sheets printed on both sides)
- template for eyeglasses (see page 8)

Materials	Quantity	Box no.
adhesive film	1	7
black construction paper	1	17
scissors	1	5
transparent film (blue, yellow, green, red)	1	17

4.1.2 Organizational aspects

Facilities	In the classroom or outdoors
Time required	Approx. 45 minutes
Experimental variations	As a station for learning at stations; see the notes in chapter 4 The eyeglasses can also be cut directly out of the film and then secured using a rubber band. It might be necessary to cover the sharp cut edges of the film with transparent adhesive film to prevent cuts.
Safety information	See the “Safety information on the topic of health” guide book binder.
Cleanup	The eyeglasses with colored film can be reused by the next group. Depending on the consumption of materials, the students can take the homemade eyeglasses home.

4.1.3 Explaining the subexperiment in the teaching context

The students will make eyeglasses with films of different colors and wear them to change their color perception. They will look through the glasses at pictures and different objects in their surroundings and observe how the objects’ colors transform.

Technical background

Visible light is electromagnetic radiation with a wavelength ranging from 380 to 780 nanometers (nm) and represents the only range of the electromagnetic spectrum that is detectable by the human eye. Ultraviolet, X-ray, and gamma radiation have shorter wavelengths (< 380 nm), and infrared radiation, microwaves, and radio waves have longer wavelengths (> 780 nm). In simple terms, we can say that light of a certain wavelength has a certain amount of energy and this wavelength or energy corresponds to a certain color. The smaller the wavelength is, the shorter the wavelength of the radiation is and the more energy the radiation has.

The sensory cells in our eyes react specifically to the energy and our brain assigns each energy level or wavelength to a specific color. For instance, if our receptor cells are stimulated primarily by light with a wavelength of 450 nm, we see the color blue; if they are stimulated by light with a wavelength of 590 nm, we see yellow. (The sensory cells in our eyes that are responsible for color vision are called cones; see subexperiments 2 and 3.)

How do we perceive a color when we look at an object of a certain color?

All substances have the property of reflecting light with certain wavelengths unchanged and absorbing light with other wavelengths. White light, such as the light that comes from the sun, contains light of all colors in all intermediate shades from red to green to blue. If a piece of white paper is illuminated with white light, for example, it reflects light with all wavelengths, thus all colors. The object appears white to us. On the contrary, if a black object is illuminated with white light, it absorbs all light and the object appears black to us. However, if a piece of white paper is illuminated with red light, it appears red to us because the red light is reflected.

How do we see the color of objects that have a color?

If white sunlight, for example, falls on a plant leaf that mainly contains green leaf pigment (chlorophyll), this pigment absorbs the red and blue portions of visible light and reflects the green portion. We therefore see the leaf as green. In contrast, if a leaf that is actually green were illuminated with red light, nothing would be reflected and we see the leaf as gray or black.

If we wear sunglasses with a color filter, the color components that do not match the color of the lenses are “swallowed up”, which changes our color perception. With brownish-yellow or reddish sunglasses, for example, the weather looks nicer to us than it actually is because the colors of our surroundings appear closer to what they would look like in direct sunlight. (That’s why we often use the saying “seeing through rose-colored glasses” in the figurative sense. It means that things appear better than they really are.)

In living organisms, the various color vision systems have evolved over time. The reasons for this might be different selective advantages: Ripe fruits can be distinguished from unripe fruits, nutrient-rich leaves can be distinguished from nutrient-poor leaves, or reproduction partners that are willing to mate can be distinguished from those that are not willing to mate.

By the way, the determination of the wavelengths of light that correspond to certain colors is standardized according to color perception in humans. As mentioned, other living beings can perceive and distinguish light with different wavelengths; their “color space” is completely different from that of humans.

The fact that we link colors and color combinations with certain emotions or information is mainly a learned behavior: for example, black/yellow for poisonous animals, pink and light blue for babies.

4.1.4 Ask about the students’ prior knowledge and ideas

All children have experienced at some point how colors in their surroundings change when they look through sunglasses. The world almost seems to be bathed in a different light. Tinted windows in cars or buildings also change the colors of objects that they view through these windows. You can also ask the students which colors they particularly like and which they dislike. Or ask them what color they would like on the walls of their room and why. The students will thus quickly recognize that people link colors with certain emotions.

4.1.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the student experiment:

The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ Find out what different meanings colors can have. ▪ Find out why your perception changes due to eyeglasses with colored film.
Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ “Red means danger.” ▪ “Red means love.” ▪ “Colors can sometimes mean this, sometimes that.” **Related to the experiment:** ▪ “If I look through the blue glasses, everything looks really cold.” ▪ “If I look through the yellow glasses, everything seems friendly.” Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** Following the template, the glasses are made from construction paper, colored transparent films, and adhesive film (or possibly directly from the film; see item 4.1.2 “Experimental variations”). **Conducting the experiment:** ▪ The students will first look at pictures of familiar objects and symbols without glasses with colored film and take notes on the colors they perceive. ▪ Then they will look at the same pictures through the homemade glasses with colored film and think about the changed perception. ▪ The question regarding their favorite glasses fosters an awareness of individual perceptions and preferences. ▪ Encourage the students to share with each other what they perceive when they look through the film and whether details or the entire surroundings also change. They can also recognize differences in brightness using the glasses.

Observing and documenting

Most important observations:

- Without colored eyeglasses:

Pictured object	Color	Meaning of the color
Stop sign	Red	Danger
Red traffic light	Red	Danger, stop
Green traffic light	Green	Everything is fine, go
Tomato	Red	Ripe
Doctor's coat	White	Clean, honest
Baby shampoo	Pink	Gentle, for babies
Sun	Yellow	Warm
Wasp	Yellow, black	Dangerous
Mushroom	Red, white	Poisonous
Blue sign	Blue	Neutral

- When you look through the colored film, you see everything in the color of the film, or in a new color due to the (subtractive) color mixing of the two colors of the glasses and the observed object. Differences in brightness are enhanced or made less pronounced.
- Examples: "The glasses with yellow film, because then everything looks friendly" or "The glasses with blue film, because then everything looks nice and cool".

Analyzing and reflecting

Results to be expected:

1. What changes, and what remains the same:
   The observed object is usually bathed in the color of the glasses. Sometimes new colors are created when colors mix (for example, blue + yellow = green).
2. Color effect:
   The students will realize that they have similar thoughts about colors and the effects they have.
   Looking through the glasses with colored film influences the students' color perception. They reinforce their knowledge about the effect of different colors by noticing that the original information, such as "danger" or "ripe tomato", is distorted. When the students look at the wasp and mushroom it may occur to them that the important information about contrast colors is still present but not the information about the colors themselves. The contrasts are not quite as distorted as the original colors.

Reference to the story to get the students thinking about the topic:

The mother's saying about the rose-colored glasses is of course an idiom, but in the experiment, Ben can see that the world really does look nicer through glasses with rose coloring. And the small dog also makes the world nicer for Ben.

4.1.6 Other information

In the student instructions

Doing further research	Red-green color blindness can be inherited. The affected persons are not greatly restricted in their everyday life. However, there are careers that they cannot pursue. For instance, pilots are subject to strict guidelines regarding their sense of sight. They must pass vision tests before their training starts. The students can project themselves into the everyday life of a person with red-green color blindness in order to develop an awareness of the fact that all persons perceive their surroundings in their own way. In this context, they can also use the common vision test pictures for detecting red-green color blindness. Gauge for yourself whether your group of students is open to this, and be sensitive and supportive if a child finds out for the first time that he or she has a difficult time distinguishing between red and green. Far more men are affected by red-green color blindness than women due to the mode of inheritance.

Miscellaneous notes

Stroll around the neighborhood with the students and observe the surroundings with alert eyes. They will discover that colors are an important means of signaling and marking. Find further examples of consistent color designs besides the traffic signals and signs already discussed; cold water taps can be recognized based on blue marking, and hot water taps based on red marking. Trash bins have specific colors for purposes of waste separation; in addition, the trash bins that get dirtier have darker colors. Police, fire department, and mail vehicles also have individual colors.

Eyeglasses template

To make the eyeglasses frame more stable, fold it once in the middle, insert the “lenses”, and seal it with adhesive film. Then attach the side pieces with adhesive film.

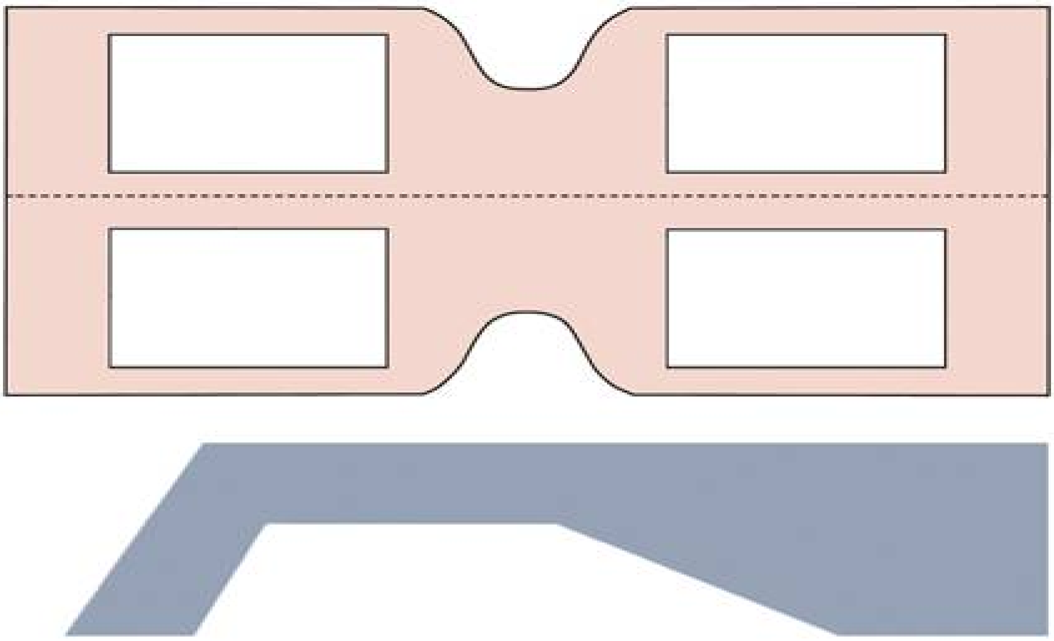

Fig. 1: Template for cutting out eyeglasses.

4.2 Subexperiment C4.2 Our field of vision

4.2.1 Apparatus and materials

Required materials that are not supplied

Materials	Quantity
Additional experiment	
different colors of clay	one ball each, approx. 1 cm in diameter

Supplied

Materials	Quantity	Box no.
electrical tape	1	6
Additional experiment		
modeling clay	1	3

4.2.2 Organizational aspects

Facilities	In the classroom or outdoors
Time required	Approx. 45 minutes
Experimental variations	As a station for learning at stations; see the note in chapter 4
Safety information	See the “Safety information on the topic of health” guide book binder.
Cleanup	Place clean clay back in the kit.

4.2.3 Explaining the subexperiment in the teaching context

The students will learn what the term “field of vision” means and determine the horizontal range of their own field of vision. They will understand the advantage of a field of vision with two eyes compared with a field of vision with one eye. In the additional experiment, the students will find out that they cannot perceive colors everywhere in their field of vision.

Technical background

Our **field of vision** is the area of our surroundings that we can view with both eyes at the same time without moving our eyes or head. The horizontal and vertical range of a person’s field of vision depends on age, gender, and level of attention. Adolescents’ field of vision is approximately 175°, and the value steadily declines as people age. The field of vision is somewhat greater for women, and it temporarily shrinks when we concentrate on an activity or when we are experiencing stress. Each eye has a field of vision of approximately 150°, meaning that the fields of vision of the individual eyes overlap by about 120°. However, since we normally move our eyes back and forth automatically, our field of vision seems larger. We can take in an approximate range of up to 270° without turning our head.

Even though our field of vision is approximately 175° or 270°, there is only one area of this range where we can focus clearly. To prevent an overload during image evaluation, our brain always evaluates only a fraction of the field of vision per unit of time. Therefore, depending on how closely we focus on details, the area where we can in fact see clearly at any given time is approximately between 3° and 50°. If we nevertheless think that we always see everything clearly, that’s because our brain restores the other areas not actually evaluated at this point in time from memory as clear images. This phenomenon can be verified based on two practical examples:

- Many magic tricks take advantage of the fact that people see only what they are currently focusing on.
- Experience from photography shows that a lens with an angle of view of approximately 50° best corresponds to the human visual impression.

How can we estimate distances and see three-dimensionally?
These abilities are based on **binocular vision**. In people with normal vision in both eyes (with or without eyeglasses or contact lenses), the brain receives two slightly different images from the left and right eyes. This difference depends on the viewing distance. To obtain a common focused image, the brain shifts the two images toward each other until they are congruent. Depending on our distance from the objects that we see, the brain must shift the images to a varying extent so that they congruently form one image. Because this process takes place automatically in our brain, we constantly have information about how far away objects are so that we can see three-dimensionally. (By the way, people with one eye can also see three-dimensionally. In this case, the brain learns to estimate the distance based on perspective, that is, the perceived reduction in the size of objects as the distance from them increases.) As a result, when we reach for an object, we usually judge the distance needed quite accurately.

The sensory cells in our retinas, the rods and cones, are not distributed uniformly. The cones, which are responsible for color vision, are mainly located in the middle of the retina. In contrast, the rods are primarily found on the periphery of the retina. This means that we cannot perceive any colors on the periphery of our field of vision. We don’t notice this in everyday life because our brain simply automatically fills in this information from experience. This fact can be experimentally demonstrated very well.

4.2.4 Ask about the students’ prior knowledge and ideas

It’s clear to the students that the range of the field of vision changes when they close one eye. The students may be familiar with situations in which it would be practical if we also had eyes in the back of our heads. Ask them what people do when they cannot see something, such as when riding a bicycle.

4.2.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the student experiment:

The research question ?	The following alternatives to the research question stated in the student instructions are possible: ▪ Find out the range of your field of vision.

Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ "I can see from left to right." ▪ "I can see more than/less than 180 degrees." **Related to the experiment:** ▪ "When I turn my head, my field of vision changes." ▪ "When I squint, my field of vision gets smaller." Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** To conduct the experiment, the students need only their eyes, their thumbs, and the lightest possible wall so that they aren't distracted. **Conducting the experiment:** ▪ Make sure that the students fix their gaze on the wall and do not look at their thumbs. In addition, they shouldn't squint. ▪ The students might cheat because either they sense some competition or they still see their arm but interpret it as their thumb. Instruct them to wiggle their thumbs; they can really still see their thumbs only if they can perceive the wiggling. ▪ The students must close one eye for the experimentation phase with individual eyes. Not all people can tightly shut their eyes independently from one other. Provide assistance, or instruct the team partners to gently cover the eye. They can also cover one eye using eye patches or towels.
Observing and documenting	**Most important observations:** ▪ The students will observe that their fields of vision differ. The pieces of tape on the floor help with the comparison. However, large differences are not expected. ▪ Things become interesting when they compare the fields of vision: The students will determine that the fields of vision of their left and right eyes overlap to a large degree. ▪ The team partners' hands normally do not meet each other exactly when each of the partners has one eye closed. If the students are familiar with angle measurements, they can measure the angle of their own field of vision using the pieces of tape. They could also record their field of vision as a drawing.

Analyzing and reflecting	**Result to be expected:** The overlapping of the fields of vision of our two eyes has the advantage that our brain receives two pieces of information about everything that we look at and we thus can see three-dimensionally. Correct/incorrect answers: (The following answers are correct only if the student innately sees equally well with each eye.) With two eyes … ▪ I can see especially precisely what is happening in my line of vision. (true) ▪ I can see everything double. (false) ▪ I have a larger field of vision. (true) ▪ I see twice as clearly. (false) ▪ I can estimate distances quite precisely. (true) ▪ I can see three-dimensionally. (true) By reflecting on the different angles of view, the students become aware of the significance of the field of vision. They will realize that we perceive not only the things that are directly in front of us, but also some things that take place at our sides. **Reference to the story to get the students thinking about the topic:** Ben now knows that he isn't in Mr. Rabe's field of vision when Mr. Rabe is writing on the board. Ben must therefore be patient until Mr. Rabe turns around (so that the area he is viewing changes and he can see Ben). Moving your head doesn't change your field of vision; only the area being viewed changes.

4.2.6 Other information

In the student instructions

Doing further research	In this additional experiment, the students will find out that they are incapable of determining the color of an unknown object that is gradually introduced from the rear into their peripheral field of vision. Allow them to conduct as many rounds as they need until it is clear that they cannot reliably determine the color until the object has come within a certain range of their field of vision. It's true that we can recognize some colors earlier. Observe the following: ▪ The team partner must move his or her thumb leading with the colored clay, since otherwise the color impression of the thumb will interfere. ▪ The team partner's arm must not move into the test person's field of vision. ▪ The team partner should move his or her thumb gradually enough so that the test person has enough time to say "stop". The fact that we cannot see any colors in the peripheral area of our field of vision is quite amazing to the students. If the students recognize the colors unusually quickly, they are probably using balls of clay that are too large and must experiment further with smaller balls of clay.

Miscellaneous notes

As a further activity, you and the students could think about where animals' eyes are positioned (for example, fish, big cats, horses, or birds). Allow the students to research how these animals see. Do their fields of vision differ from ours? If so, what could be the reason?
Animals that are hunted typically have eyes on the sides of their heads so that they can see attacking enemies early or can keep a close eye on their escape route. In contrast, hunters typically have forward-facing eyes so that they can optimally locate their prey.
Discuss the importance of horse blinders with the students. Make blinders together with the students and take a short walk as a group.

4.2.7 Reference to values

What is your opinion?

In the discussion about values for this experiment, the teacher can provide a prompt or tell a story in which a problem is posed. Both actions lead to a discussion based on reflections. What's important is that the reference to values can be established in the experiment. The discussion can focus either on values related to the learning process (for example, working reliably in groups) or on object-related values (for example, handling paper as a resource). The student instructions for **C4.2 Our field of vision** address object-related values.

Object-related dilemma: An object-related dilemma can be integrated in the discussion of the values "solidarity", "openness", "initiative", and "acceptance of responsibility" at the end of the student instructions. The students should express their opinions about it.

Dilemma regarding eyes:
You are going home with your friends. You notice a boy who wants to cross the street. He is holding a walking stick and has an eye patch over his right eye. Your friend whispers to you, "Look, that boy can only see with one eye." You nod to your friend and say, "Maybe we should help him cross the street." Your friend frowns. "What for? The boy can't see anything with the one eye, but his other eye is perfectly healthy. Let's go. We're already late."
Think about it: What would you do?

Possible examples of students' statements for and against helping:

Reasons for helping	Reasons against helping
▪ His field of vision is restricted. ▪ He cannot safely cross the street by himself.	▪ He can still see with one eye. ▪ It will take too long and you're already late. ▪ It's time-consuming to ask the boy.

Objective: The students should reflect upon how they can handle the situation while demonstrating solidarity, openness, initiative, and responsibility. The values of solidarity, openness, initiative and acceptance of responsibility are addressed.

Alternatives: Statements or questions as prompts related to the story told in the student instructions are also suitable for encouraging discussion. The values remain the same.

- **For discussion:** You observe a child who looks only straight ahead while crossing the street.
- **Question for discussion:** Why is it important to know how wide your field of vision is?

Notes: The students should reflect upon values and express their opinions. It may turn out that several values are addressed.

4.3 Subexperiment C4.3 You need light to see

4.3.1 Apparatus and materials

Required materials that are not supplied

Materials	Quantity
blanket	1
solid-colored, identical building blocks in yellow, red, green, and blue	as desired

4.3.2 Organizational aspects

Facilities	With a table in the classroom
Time required	Approx. 45 minutes
Experimental variations	As a station for learning at stations; see the note in chapter 4
Safety information	See the "Safety information on the topic of health" guide book binder.

4.3.3 Explaining the subexperiment in the teaching context

The students will test their ability to see in the dark and sort different-colored objects in the dark.

Technical background

Our ability to see and our perception of colors greatly depend on lighting conditions. Our visual sensory cells, the rods and cones, begin working at different levels of illuminance: Rods are very sensitive to light and are already activated in poor lighting conditions; even just moonlight or the twinkling of stars is sufficient for them. However, the rods can perceive only differences in light intensity, meaning gray tones, but not colors.
Cones, which are responsible for color vision, are activated only at higher levels of illuminance. That's why we can barely perceive colors in poor lighting conditions. Our pupils therefore fully dilate at dusk and in the dark so that as much of the sparse lighting as possible can reach our retinas.
The transition to seeing with our rods takes a little time. Our eyes do not adjust to seeing in the dark for approximately 10 to 20 minutes, and after that we recognize more. In contrast, the transition to sudden brightness goes very quickly for protection reasons. Our eyes get used to the dark faster if we close them for a few minutes. However, we lose our color vision after this adaptation.

4.3.4 Ask about the students' prior knowledge and ideas

Children experience early on that their ability to see in the dark is limited. This is why younger children are sometimes afraid of the dark.
The students are also familiar with sudden changes in lighting conditions, for example, when a car enters a tunnel or when they enter a poorly lit room. Ask them about their sensory impressions in moments like these. Maybe the students already know that their eyes must get used to the dark.

4.3.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the student experiment:

The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ Find out what colors look like in the dark.
Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ "I can see outlines." ▪ "I can't recognize anything at all when it is really dark." ▪ "I can distinguish only gray tones in the dark." **Related to the experiment:** ▪ "I can easily tell the yellow building blocks apart from the other colors of building blocks." ▪ "It's extremely difficult to distinguish between the dark colors, blue and green." Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** It's convenient if the room or the corner where this experiment is set up is poorly illuminated. As an alternative, this experiment can also take place in a separate room. Be mindful of your supervision requirement in this case. **Conducting the experiment:** ▪ The students will explore their color impressions in the dark, first individually, then as a team. The students in the cave should avert their gaze when the objects are handed into the cave so that they cannot recognize the colors in advance.
Observing and documenting	The students will learn what limitations there are without light. **Most important observations:** ▪ At first it is very difficult to sort the colors in the dark. ▪ Once the students' eyes have gotten used to the dark, they can better perceive differences in brightness; they see more than before. ▪ After adaptation, it is possible to distinguish between lighter and darker colors (for example, between yellow and blue). Although the students can see better after their eyes adjust to the dark, it's hardly possible to precisely sort the colors; for example, there are difficulties in distinguishing blue from green.

Analyzing and reflecting	**Results to be expected:** 1. Answer to the cloze test: I can identify the colors poorly in the dark. It is particularly difficult to distinguish blue and green from each other. If you let your eyes get used to the dark, overall you can see better in the dark. After letting my eyes get used to the dark, I can identify the colors just as poorly/slightly better. 2. It's possible that the students will insist that they can see the colors slightly better after adaptation. In this case, explain to them that it's primarily the contrasts between light and dark colors that they can recognize better after adaptation. However, to preserve their individuality, you can allow both versions in the last sentence of the cloze test. **Reference to the story to get the students thinking about the topic:** Ben's explanation that some pirates wore an eye patch so that at least one eye was used to the dark when they went below deck could be true. **Transfer:** The difficulty in sorting the colors helps the children realize how important light is for our color vision. They could discuss why people should wear light-colored clothing when they jog or walk in traffic when it is dark outside.

4.3.6 Other information

In the student instructions

Doing further research	For homework, the students could explore their rooms in the dark. Specify once again that they must tell their parents what they plan to do for safety reasons. The students will darken their rooms; they should then look for particular objects. They will move very slowly and increasingly rely on their sense of touch. They can also close their eyes to let their eyes get used to the dark Depending on how tidy the room is, the assignment will work better or worse. Ask the students about their experiences the next time you meet with them.

Miscellaneous notes

- With the students, consider how it would be to live in a world without light. The sun shines on our planet. Without sunlight, it would be dark and very cold on Earth. Without light, we would be unable to perceive the magnificence of colors in our surroundings, and we would be unable to see objects. In the cold darkness, no plants would be able to grow, and living beings including people could not exist.
- Investigate color perception in animals. There are lots of animals that perceive fewer colors than we do or only gray tones. Are there also animals that can perceive more colors than humans can?

4.4 Subexperiment C4.4 Where do the colors of the rainbow come from?

4.4.1 Apparatus and materials

Required materials that are not supplied

Materials	Quantity
smooth drinking glass	1
water	1 glassful

Supplied

Materials	Quantity	Box no.
white construction paper	1 sheet	17
prism	1	9

4.4.2 Organizational aspects

Facilities	At a simple table in the classroom in front of a window or outdoors; sunlight is required for all experiments.
Time required	Approx. 45 minutes
Safety information	See the “Safety information on the topic of health” guide book binder.

4.4.3 Explaining the subexperiment in the teaching context

The students will work with the colors of light and use two methods to learn that you can disperse white sunlight into its individual colors (spectral colors).

Technical background

Light normally propagates in a straight line. If it impinges on a boundary between two different translucent substances, such as air and water or two different types of glass, one part of the light is reflected and the other part is transmitted through the boundary, which changes the light’s direction.
The latter action is called **refraction**. The light is “bent” unless it impinges on the boundary perpendicularly. Different materials refract the light to varying degrees, which is described by the refractive index typical for the material.

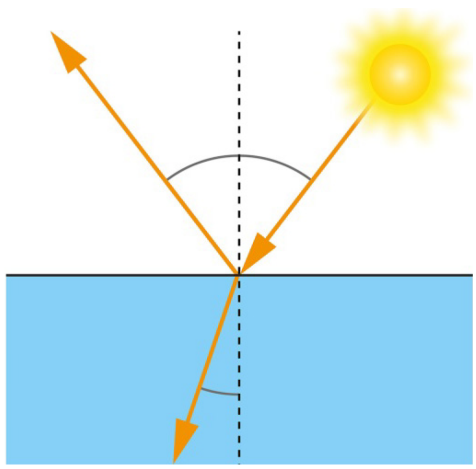

Fig. 2: The principle of refraction.

The degree to which the light is bent, or refracted, depends not only on the angle of incidence, but also on the material the light enters at the boundary. For instance, when light transitions from air to water, it is refracted toward the axis of incidence. In addition, the degree of bending also depends on the wavelength of the incident light. This is called **dispersion**. For example, in a drop of water, red light is refracted less than blue light, which results in the atmospheric phenomenon of a rainbow. And due to dispersion, light is also separated into its colors when it passes through a prism.

Notes:

- The occurrence of a rainbow in nature is an extremely complex physical circumstance. Refraction and dispersion explain only the color composition of a rainbow. These two facts are insufficient for explaining the arch shape or the phenomenon of a secondary rainbow.
- Light is always absorbed to a certain extent when it passes through a material, even for an apparently completely transparent material; in other words, the radiant energy of the light is converted to heat. As a result, the intensity of the transmitted beam is lessened. This is one reason why the students can see the refracted light in the experiments only in a darkened room.

4.4.4 Ask about the students' prior knowledge and ideas

Most students have certainly seen a rainbow before. The students are probably not aware that the colors of the rainbow are contained in the colors of sunlight. Do a test: Can the students say which colors definitely occur in a rainbow? Can they even name all colors, and in the correct sequence? What color is at the top, and what color is at the bottom?
The students have probably perceived refraction effects at some point, even if unknowingly. Before beginning with the experiment, you can conduct a simple demonstration so that the students can experience the bending of light at boundaries. Place a drinking straw in a glass of water. If the students observe the glass from the side, the drinking straw looks broken or warped. The effect is even more pronounced if you add approximately 1 cm of cooking oil on top of the water. Then the light beam is broken twice. Maybe the students themselves have come away empty-handed at some point when they tried to fish an object out of water because they saw the object at a different location than where it actually was. It's also funny when you stand waist-deep in a swimming pool and look into the water at yourself: Your own body seems to have completely different proportions.

To understand the experiment in detail, the students would need to already have the idea that light propagates as a beam. If the students do not have prior knowledge regarding the concept of a light beam, they do not necessarily have to acquire it. It suffices if you carry out the experiment to discover the various fascinating properties of light.

4.4.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the student experiment:

The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ What color is sunlight?
Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ "Sunlight is yellow/white/red." ▪ "Sunlight is red in the morning and evening." **Related to the experiment:** ▪ "There's a rainbow in the water glass." ▪ "The prism discolors the light." Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** ▪ All experiments should be conducted in direct sunlight. The colorful spot should ideally be observed in a darkened area. Otherwise, the unrefracted sunlight would overlap with the refracted, weaker individual colors of light, making them "invisible". ▪ Walk around the surroundings beforehand and point out suitable locations to the students: Outdoors: in the shade of a tree or a building In the classroom: at a dark windowsill or table that is not located in direct sunlight. **Conducting the experiment:** ▪ Provide assistance in the placement of the individual elements relative to each other: sheet of paper, glass of water, prism, sun. ▪ Looking through the prism is safe for the eyes even in direct sunlight because the prism doesn't bundle the light like, for example, a magnifying glass. Nevertheless, you should point out to the students that they should generally avoid looking directly into the sunlight in order to protect their eyes.

Observing and documenting

- When a prism is held next to the wall or a sheet of paper, a colorful spot of light appears. However, when the students look through the prism, the colorful spot is cast directly on their eye.
- When you look through a prism, you normally see the observed objects with a color fringe. The effect results from the wavelength-dependent refraction.
- The shape of the colorful spot may differ through the glass and the prism, but the colors it contains are the same.

The most important observations:

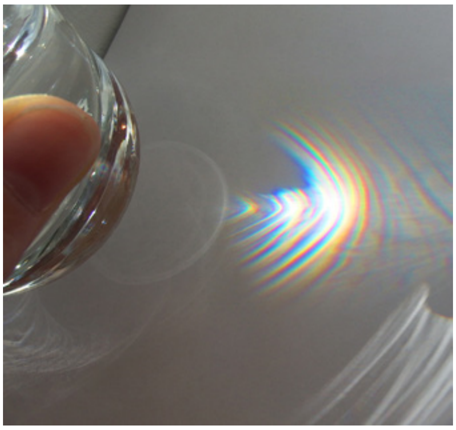

Fig. 3: Observation using a water glass.

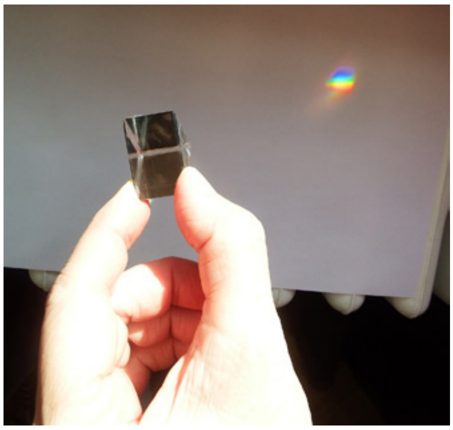

Fig. 4: Observation using a prism.

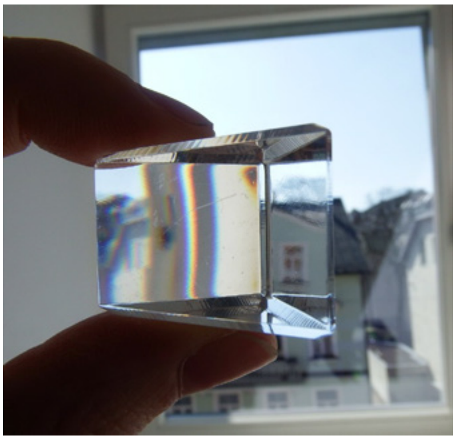

Fig. 5: What you see when you look through the prism.

Analyzing and reflecting	**The most important results:** 1. Number of colors and the sequence: Depending on how closely the students observe, they can see up to six colors in the following sequence: Red – orange – yellow – green – cyan – blue (purple). Make sure the students name the correct colors (for details, see section 4.4.7). 2. The colorful spot appears when something besides air is between the light source and the eye. **Reference to the story to get the students thinking about the topic:** Mia is right: White sunlight contains all colors. The colors are thus a property of sunlight. However, the colors are visible only because refraction occurs in the water or prism. Splitting the light into its colors is thus a property of the materials (for example, water or glass). Without the materials, there would be no splitting. Viewed this way, Ben is also right to some extent.

4.4.6 Other information

In the student instructions

Doing further research	The students are given the assignment to pay attention to where a spectral separation of light occurs in their surroundings in everyday life. In addition to the natural phenomenon of the rainbow, examples include the following: ▪ A film of shimmering oil on a puddle in the street, for example, when fuel has leaked ▪ Color streaks on soap bubbles ▪ Spray created when a hose is used to water the garden (imitation rainbow) ▪ A cloud in the sky with colors in its interior, called an “iridescent cloud” It’s also possible to observe the spectral separation of light using a CD/DVD. In this case, however, this isn’t refraction, but rather a diffraction effect.

4.4.7 Reference to technology

In the student instructions

Whether in nature or in modern communication technologies, the perception and use of colors is self-evident. Nonetheless, adults as well as students are usually completely unfamiliar (or only vaguely familiar) with how the production and mixing of colors works, not only with a watercolor paint set, but also in technology in connection with light-emitting diodes or screens (for example, flat screens, smartphones).

Tracking down technology	Two photos from everyday life are shown in the student instructions: ▪ **Living room lighting with light from light-emitting diodes** ▪ **Television screen** The students should investigate a television screen more closely. Questions and tips are offered to help them.

The insights gained in the experiments are far too insufficient for the students to independently figure out the applications given in the technology examples. The teacher should therefore first allow the students to further explore the two possibilities of producing colors in the form of additional research projects.

Producing a color by mixing object colors (subtractive color mixing)

Terms: An object color is understood as the color an object appears to be when illuminated with white light.

The students' research project is to produce the colors red ("tomato red"), green, blue ("violet-blue"), and gray or black by mixing felt-tipped pens that are yellow, cyan, and magenta.
An ink-jet printer, for example, also works with these three primary colors. It's difficult to achieve this goal with the paint set because the colors are not sufficiently pure.
Note: Because names of colors are frequently used imprecisely in everyday language ("all reds are not the same"), you can use the opportunity to explain the correct color names to the students, for example, using a color wheel.

Result: What you see in lighting with white light:

- **Red** = yellow + magenta
- **Green** = yellow + cyan
- **Blue** = cyan + magenta
- **Gray to black** = yellow + magenta + cyan

Conclusion: In lighting with white light, you can produce colors and black tones by mixing object colors.

Producing colors by mixing colored light (additive color mixing):

A simple preliminary experiment can be conducted: White light is cast through a colored film (red, blue, or green) and onto a sheet of white paper or a white wall. The films included in the Experimento kit can be used for this purpose.
For further study and as an alternative to the procedure described in the student instructions, set two films upright on the table at an angle relative to each other. Illuminate each film with white light, for example, using flashlights, so that the light beams overlap behind the films and thus mix (see figure).

Result: The following mixed colors are produced behind the films:

- Red + green = yellow
- Red + green = magenta
- Blue + green = cyan

Conclusion: You can mix any colors by overlapping light of suitable colors.
The overlapping of red, blue, and green light produces white light.

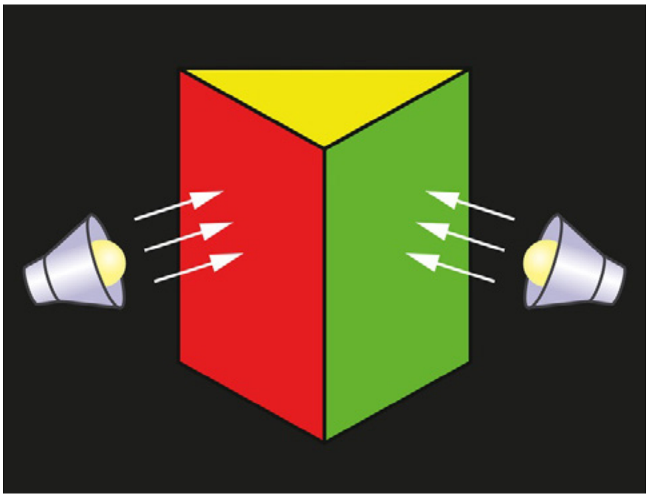

Fig. 6: Experiment setup for producing yellow from red and green light.

Information on the technology examples:

- Both technology examples are applications for additive color mixing; the colors are produced by overlapping colored light. The brightness increases in the process.
- To find out how a screen (LCD display) is built, use a strong magnifying glass (at least 10x magnification; 15x is better). The magnifying glasses included in the Experimento kit are insufficient (only 3x magnification).
- In the sample photo with living room lighting, the teacher must point out that the colored light in the lamp is produced by mixing the lights of blue, red, and green LEDs. How the colors of objects in the room look depends on their object color. When the room is illuminated with blue light, the white wall looks blue and the bowl, which is actually green, at the left on the table looks gray or black.

You will find the answers to the questions asked in the student instructions on the answer sheet in the guide book binder. In the “Experimento | 8+: Tracking down technology” media package, which is available on the media portal, you will find additional technical information compiled in an information sheet and a link list. This media package also includes the work assignment as a prepared worksheet as well as the individual photos.

Fig. 7: Control panel for mixing the colored living room lighting.