



LIGHT IN WATER

TEACHER'S BACKGROUND: THE PHYSICS OF LIGHT IN WATER

Water absorbs light. Since light is essential to plant growth and almost all living things depend on plants either directly or indirectly for their food, light is very important in aquatic habitats. As water gets deeper, it gets darker. Even in very clear water that does not have sediment or phytoplankton (single-celled algae) blocking light penetration, it looks dark at 150 m although a bit of light penetrates to 600 m. This lack of light in deeper water has two consequences. The first is that algae or plants in the ocean or in lakes grow well only within about 100 m of the surface in very clear water. In water that is TURBID (cloudy with sediment or phytoplankton), the plants or algae must be even closer to the surface. Second, rooted plants or seaweed that grow from the bottom up live in shallow water near shore.

Light is also necessary for vision, an important sense for many animals. Animals that depend on natural light for their vision are restricted to relatively shallow water in an ocean thousands of meters deep. Animals that are bioluminescent, making their own light, have an interesting solution to this lack of light in deep water. Animals that search for prey or that need to find others of their own species in shallow murky water or in deeper dark water make use of senses other than vision. These include adaptations for the production and reception of sound (vibrations in the water), chemical information, or electrical fields.

In addition to the general lack of light, colors (wavelengths of light) are differentially absorbed by water. Red and orange are absorbed first while blue penetrates best. For this reason, underwater movies or photographs made with natural light look blue. Those that show bright colors are made with artificial lights carried by the photographer. The brilliant colors we associate with some kinds of marine animals like sponges are invisible in their natural habitat. Other marine organisms like colorful coral reef fish live in shallow water where their colors can be seen and have a function. Color vision is common in fish that live in bright shallow water, but not in those that live in deeper water or way out at sea where many wavelengths of light are nonexistent.

LIGHT AND PHOTOSYNTHESIS

With the exception of unique aquatic species that live near deep ocean vents or in chemical rich, oxygen poor mud, organisms that use light for PHOTOSYNTHESIS produce the food that sustains all other living things, either directly or indirectly. Things that photosynthesize are all incorrectly called "plants" by many people, but include a wide range of organisms from the familiar higher green plants to ferns and mosses to single-celled ALGAE (phytoplankton) to multicelled algae (seaweeds) to many kinds of bacteria. All of these things produce FOOD (stored energy and complex compounds) from inorganic elements and are lumped into a group called PRIMARY PRODUCERS.

Primary producers (often simply called producers) use sunlight to provide the energy for the chemical process that takes place within their cells called PHOTOSYNTHESIS. As the name implies, light (photo) energy is used to make (synthesize) some of the compounds the organism needs. The raw materials for this process are carbon dioxide and water. The oxygen that is produced is a waste product and comes from water molecules split by light energy. The food energy these organisms produce is stored in themselves - their cells, bodies, stems, leaves or seeds.

FOOD CHAINS

The producers form the base or bottom of the FOOD CHAIN, also called a FOOD WEB by some because it is not as simple as a straight chain. (Ecologists generally use the term food chain.) Animals that eat the producers or other animals are called CONSUMERS. Consumers that eat primary producers directly are called HERBIVORES which comes from Latin roots meaning “grass-eating.” Animals that eat other animals are called CARNIVORES from Latin for “meat-eating.” Some kinds of animals eat both plants and animals and are called OMNIVORES from Latin for “all-eating.” The general term PREDATOR applies to an animal that eats other animals. The word PREY refers to the animal that is eaten. A given animal might be a predator of one species and the prey of another. For example, an ocean food chain might start with phytoplankton as the primary producers. These might be eaten by small zooplankton (herbivores) which would, in turn, be eaten by larger zooplankton (carnivores). The zooplankton might be eaten by small fish which are then eaten by larger fish - both carnivores. These larger fish might be preyed upon by very large fish such as tuna or big sharks - the top carnivores. This food chain has six links.

ENERGY AND FOOD TRANSFER

At each stage of the transfer of food from one level of the food chain to the next, the food and its stored energy are used for many different things. Some are used for growth or stored food (fat or oil). Some are undigested material lost in feces or the bodies of dead organisms. Much of the food that an animal eats is broken down in a process called RESPIRATION that takes place inside cells. In this process, oxygen combines with the carbon and hydrogen atoms in the food to make carbon dioxide (CO₂) and water (H₂O). The energy released is captured and used to do work such as movement, making new molecules or moving molecules around. Since no energy transfer is perfect, some energy is also lost as heat. Food that is broken down is said to be “burned” since the end products, carbon dioxide and water, are the same as those of combustion. Food energy is measured in calories, so animals are referred to as burning calories when they do cellular respiration.

Food burnt or broken down is gone from the food chain and not available to the animals at the next level. Consequently, each level of the food chain above the level of the producers has less available food than the level below it. The food available to the next level of the food chain is in the bodies of the plants or animals at the lower level and is called the STANDING CROP. The amount of food available at each level may be expressed as total weight or as calories.

What determines the length of a food chain? Why do some habitats have longer chains than others? First, the amount and quality of food stored in the producers has an effect. Since energy is lost at each stage, if you start with a great deal of food or with very high quality food that has lots of nutrition, there will be more left at the higher levels. Second, efficient use and transfer of energy makes for longer food chains. If the animals at one level are very inefficient and burn most of the energy they consume, they will not be making much of themselves for the next level to eat. In general, food chains in aquatic habitats are often rather long when compared with those on land, often having six or seven links in the ocean.

HUMAN IMPACTS ON ECOSYSTEMS AND FOOD CHAINS

Human activities may affect food chains in many ways. Pollution and habitat destruction cause obvious changes that is easy to see. Dead fish are hard to ignore. It is also easy to understand the consequences of filling a pond or marsh in order to build a shopping center or to add another field to a farm. The whole habitat goes away. Much more subtle changes may result from the extensive harvesting or removal of specific levels of the food chain or the introduction of ALIEN species.



When we selectively remove or add fish species, we are making changes that may have a significant impact on the other animals. Very careful planning of fishery regulations is necessary to be able to remove animals from a system on a long term basis without destroying the ECOLOGICAL BALANCE of the entire system. The result is a calculation of how many fish can be taken year after year without upsetting this balance and is called the SUSTAINABLE YIELD. People who study these problems are in a field called FISHERIES MANAGEMENT. They set fishing limits for both sport fishing and commercial fishing and enforce them. Most of the major marine fisheries under United States control are not currently being managed for sustained yield because politics, not science, determines the regulations.

Adding INVASIVE SPECIES to an ecosystem can also have a profound and unexpected outcome. They can out-compete native species or they may be too effective a predator on native species. Sometimes the additions are accidental, such as the zebra mussels which are spreading in fresh water all over the eastern United States. Sometimes the additions are done on purpose such as the carp that now live in most slow moving freshwater habitats.

EXTINCTION

The loss of species from ecosystems reduces the BIOLOGICAL DIVERSITY or biodiversity of these systems. Species may go EXTINCT. The causes of extinction were discussed in the preceding sections: habitat loss, pollution, over-harvesting and the introduction of invasive species. An example of current concern is the precarious condition of salmon in many Pacific northwest rivers. Habitat loss or alteration due to deforestation, hydroelectric dams, agriculture and invasive salmon which are genetically different than the wild salmon (all human activities) have pushed many races of salmon to the brink of extinction.

MODELING AND GAMES: LEARNING HOW SYSTEMS WORK

The concepts of food chains can be communicated to students by letting them be the animals in a simple food chain and playing a game to see who survives. The rules of the game are the rules that govern the survival of plants and animals in the wild. When they have mastered the basic rules that govern food chains, then the students can experiment with the system by changing one rule at a time (remind them - only one variable per experiment). They can ask “what if” questions, predict the answers and then run an experiment to see what happens.

This kind of SIMULATION of natural systems is a form of MODELING. Sophisticated modeling can be done with computers. Educational computer software that allows students to continue to ask “what if” questions about food chains is available from educational catalogs. Because the computer runs the simulation much faster, students can collect a great deal of “data” using a computer simulation. Such experiments might make a very nice science fair project. More sophisticated programs for high school students allow them to develop the models themselves. Students can also invent their own games which are models of biological processes.



Grade Level

4 - 7

**Duration**

1-2 class periods

Concepts

Water absorbs light.

Water absorbs different wavelengths at different rates.

Things, like sediment suspended in water, absorb light.

Skills

observing, inferring, predicting

Mode of Instruction

teacher demonstration

teacher directed group work

Materials

- underwater pictures from scuba and natural history magazines
- construction paper
- prism
- movie screen or sheet of white cardboard cut to fit projector light source with slit (cereal box weight cardboard)
- light source - air-cooled slide or filmstrip projector, strong flashlight, sun beam
- clear qt. Jar of clean water
- clear qt. Jar of dirty water (add ½ cup of fine particle dirt and shake)
- blue colored cellophane (and red and green if you have it)

LSSS

4-PS4-2; 6-MS-PS4-2

LIGHT TO "SEA" BY

**What happens to light when it moves through water? What happens to light in deep water?
Student observations.**

TEACHER'S INFORMATION

This activity asks questions about changes in light INTENSITY (the quantity) and QUALITY (the colors present) when light shines through water. The results are not clear-cut measurements, but value judgments (observations) made by students who may have different sensitivity to colors. This is a good time to discuss the use of instruments to make measurements that are standardized and to not include as great a possibility for error as human observation. If you have computer probes that measure light, you can demonstrate their use in this lab or have the students use them and compare results with student perceptions. Variability in perception means that there may be more than one answer. That is why scientists go to great lengths to avoid value judgments and to use standardized measurement.

INTRODUCTION

Different kinds of introduction for this exercise are appropriate, depending on the background of your students. Have they ever looked at a spectrum; a rainbow? Do they understand that light bouncing off of an object is reflected to their eyes? Do they know that the colors of objects are determined by which colors (wavelengths) of light they reflect? Begin with a discussion of what your students know about light. Make sure they remember the difference between quantity and brightness (INTENSITY) and QUALITY or colors of light.

LEARNING OBJECTIVES

Students will be able to:

1. Observe the effect of water on light transmitted through it.
2. Observe that substances in water affect light.

OUTLINE

Before class:

1. Prepare underwater picture cards.
2. Prepare cardboard with slit.
3. Prepare dirty water.

During class:

1. Review light and vision.
2. Compare light shining through jars of clean and dirty water.
3. Use a prism to demonstrate the color spectrum.
4. Use blue cellophane to show what happens when light shines through water
5. Have students compare underwater pictures for light quantity and quality.
6. Discuss observations.

PREPARATION

1. Prepare the jars of clean and dirty water.
2. Prepare the pictures and light source. You only need do this once as the items are permanent.
3. Sort pictures taken underwater into 4 groups: wide angle pictures in which the dominant color is blue, pictures taken close up with bright colors, wide angle pictures in which the foreground has color and the background is blue (typically a diver in the foreground), and pictures with an underwater photographer showing the camera and flash. Your goal is to have one of each kind of picture for each group of 3 or 4. If you have only one or two showing the photographer, you can share one with all the groups.
4. Glue the pictures to construction paper. If you can, laminate them for durability.
5. Prepare your light source. If you have a projector, make a cardboard square the size of a slide or part of a filmstrip and cut a thin slit in the middle about 1 inch long and 1/16 inch wide with a mat knife or razor blade. This allows you to create a nice spectrum when a beam of light is directed through the prism. Or make a round cardboard with the same size slit to cover your flashlight. If you are using a beam of sunlight, such as comes through old window shades, use a whole piece of cardboard with the same size slit in the middle. Practice using a prism and beam of light to make a spectrum of all the colors of light on a white surface.

ACTION

How does water affect sunlight quantity and quality available to plants and animals living in water? Show jars of clean and dirty water. Put white paper behind them. Tell the students you are going to shine a light through the jars. Ask the students to predict which transmitted light will be brighter: the light shining through the clear water or the dirty (TURBID) water? Which jar transmitted a greater quantity of light? Can they identify a natural event that would mimic the turbid jar? Remind them of work done in earlier activities.

Then demonstrate light quality. Use a prism and the slide projector or a beam of sunlight in a darkened room to show the colors that make up white light (prism glasses can also demonstrate this concept). Make your classroom as dark as possible so the students can see this clearly. What are the colors? What is their order

in the spectrum? The order is in increasing wavelength from blue (short) to green to yellow to orange to red (long). Have the students write the colors out in order as they observe them.

What happens if you put colored cellophane over the light source (the end of the projector lens or the flashlight) before it reaches the prism? Try it with several layers of blue and then red and green if you have them. The students should be able to see that parts of the spectrum are blocked by the transparent cellophane. It is absorbing some of the color of the material. Put increasing numbers of layers of blue over the lens. Do not discuss this.

Then ask the groups of students to address two questions. **Does water absorb light, reducing the quantity of light in deeper water? Does water absorb some colors of light more than others?** Give groups of students pictures taken underwater under natural light; everything looks blue. Pictures with close-ups will exhibit bright colors. Also show them pictures with a bright foreground and blue background. Can these differences in underwater pictures be explained? Let groups discuss their ideas for about 5-10 minutes. Have each group write its ideas and answers for the two questions. Have the class discuss and clarify its ideas. Pass around one or more pictures of divers using a camera with a flash or other light source. Does this help explain what the students have observed in the set of pictures? Compare the blue pictures with what happened when you put blue cellophane over the light. Blue is transmitted and the colors are absorbed in the same way that water absorbs some wavelengths and transmits blue.

RESULTS AND REFLECTION

Quantity of light in water: The photographs showing blue look dark. The quantity of light in deeper water is reduced just as sediment in the water reduced the quantity of light transmitted through the jars of water. Ask the students to give evidence for this from their observations.

Quality of light in water: Students should be able to state that some of the colors of light (some wavelengths) are absorbed more than other. Blues (short wavelength and high energy) are absorbed least. Reds, at the other end of the spectrum are the longest wavelength and lowest energy. They are absorbed quickest. Ask them to give evidence for this from their observations.

How do these results relate to marine and aquatic environments? Students should be able to conclude that the deeper you go in a big lake or in the ocean, the darker it gets. They should also be able to understand that suspended sediment or particles in water will block light, even in very shallow water. It is a bit harder to understand that as you go deeper, things have different colors than they do in shallow water or when a diving light is used. Illustrate with the photographs taken under the water. Those that are taken with natural light look very blue because water absorbs the other colors of light. Those taken with a flash, show colors of things that are never seen under natural conditions because the wavelengths of those colors do not exist underwater. The only way the colors show is if the wavelengths that give bright colors are brought down with the diver. In subsequent exercises, you can explore the implications of these conclusions for the plants and animals that live in aquatic and marine systems.

CONCLUSIONS

Both the quantity and quality of light available to plants and animals living in water are very different than what is experienced on land. Water absorbs light, and it absorbs the different wavelengths (colors) at different rates. In very deep water there is no sunlight.



EXTENSION AND APPLICATION

1. Some animals that live in the deep ocean communicate with light they make themselves since there is not any natural light. This light is referred to as bioluminescence because it is light made by a living thing. Fireflies are another example of the use of “living light.” If you have a flashlight for each student, divide them into “species” pairs and see if they can figure out how to find their mate in a dark room, using only a flashlight to communicate. They will have to work out coded sequences to go with their “species.” In the wild, different patterns of many lights on one animal would also work to distinguish different species in the dark.
2. The Monterey Bay Aquariums’ education staff (www.montereybayaquarium.org) designed a great activity with lantern fish. These fish live in water as deep as 1000 m or more. Students get enlarged drawings of several species of lantern fish, which have different patterns of bioluminescent lights down their side. Each student makes a fish and uses fluorescent paint from a craft store for the spots. The fish are mounted on sticks so the students can hold them up to be seen. Students in a dark classroom must find all the members of their species, demonstrating how lantern fish find mates in the deep sea.



HIDE AND SEEK

Grade Level

4 - 7



Duration

1 - 2 class periods.

Concepts

Color patterns that are easy to see in air may be very well camouflaged under water.

Skills

drawing, cutting with scissors, predicting

Mode of Instruction

individual student work

Builds on

Fish dissection activity
Activity Light to "Sea" By

Materials

For each student

- 8 inch square piece of blue cellophane (from art supply store or school art supply catalog)
- 1 ft. clear tape
- 2 ft. string
- ½ sheet heavy construction paper or card or poster stock cut lengthwise (any color, about 4.5 in x 12 in)
- pencil
- copy of goggles template (included here)

For each group

- several pairs of scissors
- stapler

For class

- pictures from activity "Light to Sea By"
- darkened room

LSSS

4-PS4-2; 4-LS1-2; 6-MS-PS4-2

What do animals see under water? Is camouflage the same below water as above? Students model animal behavior.

TEACHER'S INFORMATION

As students learned in the activity "Light to Sea By", some colors of light (wavelengths) are absorbed faster than others when passing through water, particularly the red and yellow wavelengths. Blues are transmitted best. These facts have interesting consequences for colors, color patterns, and their distribution among animals that live in water. Fish that live in shallow, well-lighted water may have color vision. But what do most fish see? Fish that live in the open ocean are generally color blind, seeing things in shades of gray. Fish that live in murky or muddy water may be almost blind and depend on touch or electrical fields to sense their surroundings. In this exercise your students will experience what the world looks like to fish that live far enough below the surface that the world looks blue, the only color to effectively penetrate very deep.

INTRODUCTION

Ask the students to write their prediction for the answer to this question: What do you think is the use of red color in fish that live below 10 m (33 ft.) in the ocean? Red color is typical of many California saltwater fish that hang out around rocks in 10 m (33 ft.) or more of water. Many shallow-water nocturnal fish are also red, and red is a very common color for deep sea animals in general. Can the students test this question?

LEARNING OBJECTIVES

Students will be able to:

1. Explore and explain why color patterns that are easy to see in air may be hard to see under water.
2. Experience the problems predators face when searching for camouflaged prey and develop foraging strategies for these prey.

OUTLINE

Before class:

1. Make goggles or have aide or students make them.

During class:

1. Have students predict the value of red color to a fish.
2. Students make red fish.
3. Teacher hides red fish in plain sight while students are out of the room.
4. Students return and use goggles to model being underwater as they search for the red fish.
5. Discuss value of red color and student foraging tactics.

PREPARATION

You may choose to have a parent or aide make the goggles and keep them as a classroom set, or you may have the class make them and keep them.

The students could make the goggles during an art class and decorate them as fish heads with opercula and pectoral fins, etc.

See Action Section for detailed instructions.

Do not laminate them as it makes sharp edges. Students should not wear them for more than 10 minutes at a time as it can temporarily bleach selective visual pigments, making the world a different color when they are first removed. This is not a permanent change and does not hurt the student, but can be disconcerting if the student does not understand.

ACTION

First the students need red fish. Have students review their knowledge of anatomy from the fish dissection activity by drawing with light pencil and cutting out a fish made of red construction paper. Did they remember paired pectoral and pelvic fins, the tail (caudal), dorsal and anal fins? Sign their name lightly on the side they drew on.

Now the students need to be able to see what fish see in 10 m or more of water. Either use pre-made goggles or have each student construct a pair of goggles using the provided pattern. Cut out the goggles template. Draw around it on stiff construction paper or tag board. Cut out the goggles. Then add cellophane. Inexpensive blue cellophane available in rolls from school art supply stores is folded in three or four layers to cover the eye holes on the goggles. Test ahead of time whether three or four layers gives the best result when looking at a red fish on a black background. The fish should disappear. The quality of the cellophane changes from time to time so testing it is useful. Tape the cellophane in place. Cut the string in half. Tie a fat knot in one end of each string and staple the knotted end of the strings to each end of the goggles. The strings are tied to hold the goggles on a child's head. Collect the goggles.

Explain to the students that they will use the goggles to see as fish see underwater. Do not allow students to wear the blue goggles for more than ten minutes.

Wearing them for a long time may temporarily bleach some of their visual pigments selectively. This does not do permanent damage, but it can feel weird to have your color vision altered temporarily. It takes much longer than 10 minutes for this to happen.

When the students are not in the classroom, distribute all the red fish around the room against solid dark backgrounds - green, blue, brown, black, magenta etc. Turn the classroom lights off and create dim light. It is dark in 10 or 15 m of water. Use a loop of tape on the back side to attach the fish to bulletin boards and audio



visual equipment, prop them on shelves, put them in corners on the floor. Hold a pair of goggles up to check that you are placing the fish against backgrounds with the same value.

Meet the class outside the darkened room with their goggles. When the goggles are in place, have the students enter the room and sit down. Tell them they are predators searching for red fish in 10 m of water. They are wearing the goggles because blue is the primary color of light that penetrates very far into water. Have them start searching for the fish at the same time. Time them if you want to repeat the exercise without the goggles.

RESULTS AND REFLECTION

Stop them before all the fish are found and have them sit back down. Remove their goggles. Now can they see the fish they missed? Why were the fish hard to see? The fish reflect only red. The cellophane allowed mostly blue light through. Under water there would be no red to see so the fish look black. If you wish, repeat the exercise without the goggles to compare the time it takes to find the fish when red is visible.

Did any students develop special foraging strategies? Have them discuss them. One of the most common is to use touch, brushing one's hand across surfaces. Whiskers (barbels) serve the same purpose on fish.

How did their prediction of the function of red color compare with their observations? Red is usually thought of as WARNING COLORATION that is warning predators that something is distasteful or even venomous. Underwater it is not seen. A fish that appears very colorful to us in air or in a flash picture, in fact, may be very well CAMOUFLAGED from predators. The fish is hard to see because red light is missing. It is being absorbed by the water and, therefore, cannot be reflected to the predator's eyes.

Use the color photographs to illustrate. Any colorful underwater photograph was shot with a flash which provided all the wavelengths of light. Any photo in which the predominant color is blue shows what the habitat really looks like under water.

Discuss how the activity was a model of animal behavior. How was it like a real world? How was it different? Why was it necessary to use a model rather than the real thing? What did the students learn by using this model?

CONCLUSIONS

You cannot make judgments about animals based on human perceptions. Fish in shallow, clear water may see things in a way that is similar to us, but fish that live in dark, murky water or deep water probably do not have color vision and may use vision very little, depending on other senses.

EXTENSION AND APPLICATION

1. What about the function of red color in fish that live in shallow, clear, brightly lighted water: coral reef fish? Have the students use the library to find pictures and descriptions of coral reef fish that are red. What do they have in common? They are all nocturnal! Red is the first wavelength to disappear at night. Red fish are invisible at night because there is no red light to see them by.
2. Have students research for other examples of red animals in the sea. There are lots, from the red of the giant Pacific octopus to red krill to the red of deep water crabs.



TEMPLATE FOR GOGGLES

