ESI Environmental Science Institute
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Peek-A-Boo In the Ocean Blue

Lesson plan for grades 9-12
Length of lesson: 1 class period
Authored by: Jesus Aguilar-Landaverde, Environmental Science Institute, January 2014

SOURCES AND RESOURCES:

- Boise State University, "Ocean Exploration Tour: Pelagic Zone"
  - http://edtech2.boisestate.edu/uriartej/573/splash.html
- PBS Media, Camouflage and Color: Lesson Unit and Video
  - http://www.pbslearningmedia.org/resource/363b214a-6aa6-4943-a748-d369bfd61269/camouflage-and-color/
- Bio-News Texas, "UT Austin Researchers Discover: Lookdown Fish Have New Way of Camouflaging Themselves"
  - http://bionews-tx.com/news/2013/06/04/ut-austin-fish-have-new-way-of-camouflaging-themselves/
- Science and the Sea, "Polarizing Fish"
  - http://www.scienceandthesea.org/index.php?option=com_content&task=view&id=515&Itemid=10
- NASA Mission Science, Anatomy of an Electromagnetic Wave
  - http://missionscience.nasa.gov/ems/02_anatomy.html
- Charles L. Braun and Sergei N. Smirnov, "Why is Water Blue?" Dartmouth College
  - http://www.dartmouth.edu/~etrnsfer/water.htm

POTENTIAL CONCEPTS TEKS ADDRESSED THROUGH THIS LESSON:

§112.31. Implementation of Texas Essential Knowledge and Skills for Science, High School, Beginning with School Year 2010-2011.

Aquatic Science:

(9) Science concepts. The student knows the types and components of aquatic ecosystems. The student is expected to:

(C) identify biological, chemical, geological, and physical components of an aquatic life zone as they relate to the organisms in it

(10) Science concepts. The student knows environmental adaptations of aquatic organisms. The student is expected to:

(B) compare and describe how adaptations allow an organism to exist within an aquatic environment; and

Chemistry:

(6) Science concepts. The student knows and understands the historical development of atomic theory. The student is expected to:

(B) understand the electromagnetic spectrum and the mathematical relationships between energy, frequency, and wavelength of light;

PERFORMANCE OBJECTIVES (in order of increasing difficulty to permit tailoring to various age groups):
Students will be able to:

- In writing, explain visible light as an electromagnetic phenomenon and as part of the larger electromagnetic spectrum.
- Recognize that white light is composed of all wavelengths of visible light.
- Through models, investigate how visible light attenuates through water as a function of depth and wavelength.
- Identify blue wavelengths as the most penetrating wavelengths in the ocean.
- In words, explain how countershading and polarization are adaptations of species to the epipelagic zone environment.

MATERIALS (per group of two):
One computer or laptop with internet access.

CONCEPTS: (non-exhaustive list)

Light is an electromagnetic phenomenon that can be described as a **wave** as part of the **electromagnetic spectrum.**

White light is composed of all colors (frequencies) of light, from red to violet.

Light can **interact** with manner in many ways, such as **reflection, transmission,** and **absorption.**

Different colors of light from the sun **transmit** at different depths into the ocean.

The **trophic level** of an organism specifies its position within a **food chain.**

The **pelagic zone** of the ocean begins at the low tide mark and includes the entire oceanic water column.

The **epipelagic zone** is the surface layer of the ocean that extends from the surface to ~200 meters (656 feet). It is also known as the **sunlight zone** because this is where most of the visible light exists before it is completely attenuated.

An **apex predator** is a predator in a food chain with few or no predators of its own. These organisms are at the highest trophic level within a food chain.

Ocean life in the pelagic zone can use **camouflage** to hide from predators or prey within a food chain.

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BACKGROUND:

The earth's oceans cover well over half of its total surface area. To date, much of the ocean remains unexplored by humans. Yet, the sciences of marine biology, physics, and biochemistry can help researchers understand some of the diversity of life in diverse parts of the seas. On a fundamental level, the interaction of visible light with water places constraints for the creation of major food webs built on photosynthesis. Coupled with other factors such as pressure and temperature, the changing depths of the ocean create conditions that species have had to overcome in order to survive.

One mechanism of this adaptation is the use of camouflage by ocean creatures. In shallow waters, species such as pygmy seahorses have evolved to mimic coral that exists in their environment in order to avoid detection by predators. Other species such as the stonefish use camouflage to hide from prey by blending in with the seafloor.

But, the open ocean presents a special challenge for camouflage: how does a fish avoid detection in a seemingly open space with no cover? It is a long-standing hypothesis that many fish have evolved to coat themselves in silvery coats to reflect impinging light from the surface in order to blend in with their surroundings. However, recent research at The University of Texas at Austin sheds new light on this idea by discovering how some species of fish manipulate light in yet another way: through polarization.

In this lesson, students qualitatively explore the Beer-Lambert law for water and report its consequences in animal camouflage adaptation in terms of both countershading and light polarization.

PREPARATION:

Given that the loading of the PhET simulation may involve downloading the applet, these should be pre-loaded onto the computers used in advance.

ENGAGE:

Why are the oceans blue?

Just like the related question, "Why is the sky blue?" the answer to this seemingly simple question is rich in understanding the most elegant—but also most complicated—description of nature at the smallest levels of modern science. Despite its length explanation, the description of light and the ocean waters interacting has profound impacts on how organisms have adapted to survive. So, the author suggests this question as an anchoring question for students.

Students may produce responses that cite the blue sky as the origin of the blue color. In other words, some students may believe that because the sky is blue, the ocean waters simply reflect the sky all across the earth.

To address misconceptions such as this, possible follow-up questions may include, “Then, why are some creeks or rivers not blue? Shouldn’t they also reflect the sky in the same way?”

Other students may invoke arguments of scattering or wavelength, but it is important to distinguish here between scattering processes in the atmosphere (Rayleigh scattering, Mie scattering) and the absorption that occurs in water. So, students should be encouraged to explain their answers if key words like wavelength, frequency, or scattering are mentioned.

A natural transition from this introduction to the investigative activity is to remind students that scientists have also asked themselves this question before. Water and light are readily available, and so as scientists in the classroom, a (simulated) experiment is a way to help understand the explanation for the “blueness” of water.

EXPLORE:

A qualitative introduction to the Beer-Lambert law

The University of Colorado at Boulder’s Physics Education Technology (PhET) team has designed a wide array of modules primarily for classroom use. So, the author of this lesson has made a few modifications to use their Beer’s Law simulation to approach the original question on the color of the oceans (and furthermore, the color of all water).

The specific module is the concentration/Beer’s law lab available freely for download or running through HTML 5 as of 2014. By selecting “Beer’s Law” at startup, the user is taken to an interactive environment involving a tank of variable solution, a laser of variable wavelength, and a meter to measure absorbance or transmittance of this laser through the tank. Other variable parameters include the width of the tank (and in turn, the path length of light traveling through it) and the concentration of the solution in mM.

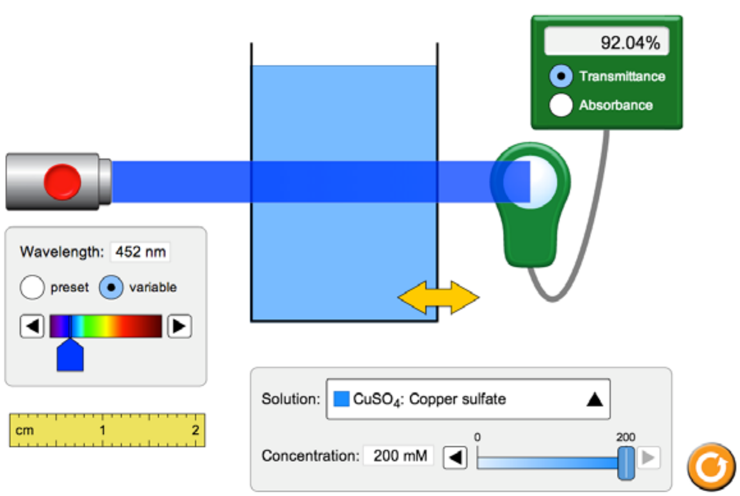

Figure 1: Sample screen of interactive Beer's Law module.

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For this activity, students are divided into small (2-3) groups, with one computer or laptop per group. Students will be investigating the relationships between "transmittance," "absorbance," "wavelength," and path length. The author writes these all in quotes since it is very likely that the definitions or meaning of these words may not yet be familiar to the students. What should be emphasized in this activity, which is intended to be purely qualitative, is the search for patterns in the values of transmittance of absorbance. Students should record their findings in complete sentences.

For example, probing questions for the instructor during student activity may include:

- Varying the size of the container, how can we make the transmittance go up?
- Is this true for all colors?
- What about by changing the color and keeping the container size constant?
- What if we ask these two questions about absorbance instead?

<u>Note to instructor:</u>
These are the patterns that are central to addressing the original question of the "blueness" of water. However, the author points out that there is a mild case of sleight of hand in the adaption of this module for this lesson. As it stands, the module does not have an option for simply water, so the author recommends choosing the "Copper sulfate" option from the available solutions and having the students keep the concentration of the solution at a constant value throughout. Although it is true that a copper sulfate solution has very different properties than water, for this qualitative investigation, it is serendipitous that the transmittance of this solution varies just as that of water: significantly lower in the red and highest in the blue, with slight increases as one approaches the ultraviolet (in water, this corresponds to electronic transitions). Therefore, the students should be reminded that this solution is *not* water, but for this exercise, we can use it to *model* pure water since it is known that these respond to visible light similarly [since $CuSO_4$ is also is blue].

<u>EXPLAIN:</u>
At this point, the instructor recollects the attention of the entire class, and the students' findings should be discussed. In particular, patterns in the experiment should be a major focus of discussion. This allows room for posing the original question once more, what could give the oceans their blue color? At this point, too, formal definitions for many of the terms found in the module. In particular, it should be emphasized that *white light* (including light from the sun) is composed of *all* wavelengths of visible light.

The Beer-Lambert law in its full formalism is not the focus of this lesson, but nevertheless the students explore three key components of it.

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- Absorbance is inversely related to transmittance
    - "The higher the absorbance, the lower the transmission"
- Absorbance increases with path length
    - "Light going through more 'stuff' comes out dimmer."
- Absorbance for the water model increases for redder wavelengths and decreases for bluer wavelengths
    - "Red light is absorbed more than blue light"

<u>Thus, water is *blue* because water *absorbs* more of the red end of visible light, so the color we see is the part of the visible spectrum not absorbed.</u>

A possible transition for the next portion of the lesson may be,
"*So we know why water and oceans are blue, but so what? Can we use that information to understand anything else? What else is in the ocean besides just water?"*

This is not meant to *devalue* the importance of understanding physical chemistry (*not at all!*), but rather it is a *liaison* between the physical properties of water and the *connection* it has to marine life and <u>***adaptation***</u>.

<u>**ELABORATE**</u>:

Now, the author proposes a rather grim thought experiment for students to imagine. Out in the open ocean, far, far away from shore, there are complex food chains in place from photosynthesizing microorganisms to hyper carnivores like blue sharks and orcas. Building upon the discoveries made earlier on the transmittance of water, it follows that visible light can only penetrate the ocean to a finite depth. This has significant consequences for primary consumers such as *phytoplankton* that use *photosynthesis* to produce energy. As a result, organisms spanning multiple *trophic levels* are found in the *epipelagic zone* of the *pelagic zone.*

So, if one imagines herself or himself as a lone fish in these exposing waters, one faces the following conundrum:

If one is not the *apex predator* in the region, but one still depends on primary consumers in this zone for food, <u>*how does one hide or avoid being eaten by predators?*</u>

Here, camouflage surges as an adaptation, and so students may be asked how it is that organisms can camouflage in open waters. What sorts of traits might be beneficial to have as a creature vulnerable to predators?

Traveling in numbers is an effective and often used strategy by schools of fish, but *countershading* is one adaptation that allows both prey and predators to camouflage with water as seen from above of from below.

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However, new evidence shows that some species of fish can actually manipulate the way light reflects off of them to effectively 'blend in' with the deep blue waters around them.

EVALUATE:

As an exit ticket, students should provide short answers to the following questions in full sentences.

1. In your own words, what is light?
2. What gives the ocean its blue color?
3. Why are so many consumers in oceanic food chains constrained to the epipelagic zone? Explain two ways that ocean creatures can use camouflage in this environment.