Do you see what I see?

Light, sight, and natural selection

Lesson 5: What color do fish see?

I. Overview
Using the penny-pecking protocols established in Lesson 4, students will examine how the environment impacts what color fish prefer to peck in Lesson 5. The activity in this part of the lesson develops connections between the human example in Lesson 3 and other organisms by having students develop an investigation using guppies and findings from Lesson 4. By drawing on what they learned about optics and sensory physiology in Lesson 2, student investigate how variations in optical properties of the external environment can lead to variations in an animal’s visual perceptions and, consequently, its mating and food preferences. In addition, the concept of variability within biological populations is addressed. This lesson also emphasizes the development, testing, evaluation and revision of a hypothesis based on prior knowledge and intuition developed from related experiments.

Connections to the driving question
In this lesson, students learn how different species of guppies perceive different colors depending on their environment. Students learn that due to the different environments fish evolved in, different species of fish will respond to colors differently. This gives students the background to understand the evolution of the visual system and variability in the visual system.

Connections to previous lesson
In the previous lessons, students sorted colored candies under different colored lights in order to observe the effect that the environment can have on perception of color. Students also learned how fish perceive color and methods for measuring this behavior. This lesson continues to build on methods and concepts introduced in these previous activities and challenges students to apply their understanding to design an experiment to test how different environments change a fish’s color preference.

II. Standards

National Science Education Standards

Science as Inquiry
- Identify questions and concepts that guide scientific investigation (pg. 175)
- Design and conduct scientific investigations (pg. 175)

The Behavior of Organisms
• Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses either can be innate or learned. The broad patterns of behavior exhibited by animals have evolved to ensure reproductive success. Animals often live in unpredictable environments, and so their behavior must be flexible enough to deal with uncertainty and change. (pg. 187)

• Like other aspects of an organism's biology, behaviors have evolved through natural selection. Behaviors often have an adaptive logic when viewed in terms of evolutionary principles.

• Behavioral biology has implications for humans, as it provides links to psychology, sociology, and anthropology.

Benchmarks for Science Literacy

Scientific Inquiry
• To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it. A hypothesis that cannot, in principle, be put to the test of evidence may be interesting, but it may not be scientifically useful. 1B/H9** (SFAA)

Diversity of Life
• The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions. 5A/H1a

Evolution of Life
• Natural selection leads to organisms that are well-suited for survival in particular environments. 5F/H6a

III. Learning Objectives

<table>
<thead>
<tr>
<th>Learning objectives</th>
<th>Assessment criteria</th>
<th>Found in lesson</th>
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<tr>
<td>Evaluate how the visual environment affects both visual perception and color preference, with regard to finding food and mates</td>
<td>Evaluations will vary and be specific to the group and include the data collected in the different environments from the different species.</td>
<td>Through the activities when turning on different bulbs</td>
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<tr>
<td>Propose, test, evaluate and revise a hypothesis based on information obtained and insight gained from previous lessons</td>
<td>Hypotheses should clearly state an explanation for known relationships and propose a test to prove or disprove the stated theory.</td>
<td>Prior to and following main lesson activities</td>
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<tr>
<td>Design an experiment to test a hypothesis</td>
<td>Experiment should include a clear and logical test of the specific hypothesis with appropriate plans</td>
<td>Prior to main activities</td>
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<td>for data collection.</td>
<td>Classroom discussion should stimulate alternative explanations to specific hypotheses based on classroom data collection.</td>
<td>Following main activities</td>
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<td>Compare results from multiple different experiments and assign meaning to their differing results</td>
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**IV. Adaptations/Accommodations**

Depending on the disability itself and taking into consideration other factors affecting the students’ ability to succeed academically, the teacher may implement several modifications such as additional visual support, instructional scaffolding, additional time for processing the information, alternative media such as audiotapes, or large-print materials, and additional time to complete the assigned readings.

**V. Timeframe for Activities**

It is conceivable to carry out Lesson 5 in a single day, but it will most likely span two. Consider having students carry out their penny-pecking experiments on the first day and concluding at the beginning of the second day (if necessary), while saving the majority of the second day for data analysis.

**Opening of lesson**

- Lesson Introduction: 15–20 min

**Main part of lesson**

- Penny Pecking Activity: 10–12 min/group
- The Island of the Colorblind Activity: 15 min/group

**Discussion and conclusion**

- Whole-Class Discussion on Data Analysis: 25–30 min

**VI. Advance Preparation and Materials**

**Materials**

- Fish tanks from Lesson 4
- Data from Lesson 4
- Penny pecking activity student packet for each group of students
  
  *(U1_L5_StudentPacket_PennyPeckingActivity.docx)*
- “Island of the Colorblind” student packet for each group of students
  
  *(U1_L5_StudentPacket_IslandOfTheColorblind.docx)*
- 3 desk lamps for each station (six total)
• Colored light bulbs: 2 red, 2 blue, and 2 green
• 2 four-color penny wheels (red, blue, magenta, yellow), described in Lesson 4 Materials
• 2 stopwatches
• white paper

Preparation
• Before class, summarize the major conclusions drawn at the end of Lesson 4 on the board. This could consist of a qualitative or quantitative chart showing which colored pennies the guppies (or different strains of guppies) preferred.
• Aquariums should be positioned so 3–4 students can easily observe the entire tank, similar to how they were situated during Lesson 4.
• Three desk lamps, each with a different monochromatic light bulb, should be plugged in next to each aquarium. Alternatively, check to see if monochromatic light bulbs fit into the aquarium light cover. If they do, the additional desk lamps will not be necessary.
• Remove the covers and turn off the aquarium lights in both tanks (do this as close to the beginning of the period as possible).
• Remember to replace the aquarium cover and light at the end of the period.
• Place a penny wheel and stopwatch at each station.
• Distribute one group data sheet to each group. This will allow the groups to submit their data to the teacher so that the teacher or a representative can enter it into the class spreadsheet.
• Whole-Class Discussion (after the Lesson 5 penny-pecking activity is completed): Before class, divide the board into partitions equaling the number of student groups. Each student group will use its space on the board to report its data from the penny-pecking experiments.

Safety
Of the utmost concern in this lesson is keeping water away from any electrical appliances (e.g., the desk lamps and light bulbs). Students should also be aware that the desk lamps become hot over time while in use.
VII. Lesson Implementation:

Opening of the activity

Begin the lesson by having students review what they did in Lesson 4 and to begin to think about how one could extend the activity to new situations. Possible questions to use in the opening discussion include:

- What were some of the major conclusions you drew about the guppies’ penny-pecking preferences?
- What would happen if you performed the penny-pecking procedure under different colored lights?
- In Lesson 2 with the colored candies, we saw how the environment impacts our own color perception. Do you think that the color light will change the color preference of the guppies?

Tell students that in this part of the lesson, they will combine Lesson 4’s guppy penny-pecking activity with the colored candies activity in Lesson 2 by having fish perform penny-pecking under different lighting conditions.

**Teacher Content Knowledge**

Guppies possess roughly the same kind of retinal cone cells that humans do—that absorb light at red, green and blue wavelengths—in addition to two other varieties.

Ask students the following questions to have them start thinking about how and what guppies see.

- How do you suppose a yellow penny would appear to the guppies if it were illuminated by blue light?
- If the guppies pecked frequently at a yellow penny under white light, how would this change when the same yellow penny is illuminated under other colors of light?

Explain to students that before they plan new penny-pecking experiments involving different kinds of lighting, it will be important for them to evaluate the protocols they use for the penny-pecking experiments they conducted in Lesson 4.

**Scientific practices: Designing investigations**

A standard practice in science is to use and manipulate old protocols from previous data collection for new investigations. Now that the students have a protocol they know how to use they should be able to manipulate it to best fit their new research question.

Have the students describe the penny-pecking protocol they used in Lesson 4.
What worked in general?
What would they change in order to improve the investigation?

Have a whole-class discussion about what investigation they will want to do in today’s activity.

What did they learn from Lessons 2 that they could combine with yesterday’s penny-pecking experiment to learn more about the guppies?

**Teacher Pedagogical Knowledge**
A common process in science is to share thoughts and ideas to build a greater understanding of the question at hand. Promoting discussion in a science classroom is important because students need a forum to “talk science”, hear the ideas of their peers, and evaluate their own understanding to make sense of what they are learning and observing.

Explain that one possibility could be that each student group looks at a single guppy strain under three different colors of light. Alternatively, groups could look at multiple strains under the different light conditions.

It is OK if two groups look at the same strain, or if a group only has time to test its strain under 2 of the 3 light bulbs, but, an effort should be made to have the class look at as many strain/lighting combinations as possible, to improve class discussions for hypothesis revaluations.

Have students create questions that they want to investigate using the same framework that they used in Part 1.

Tell students that they will need to draw upon their experiences from the penny-pecking, colored candies and spectrophotometer activities to develop hypotheses that they wish to test in today’s penny-pecking experiment.

**Scientific Practices: Planning and carrying out investigations**
To properly plan their experiment students must choose their variables and develop a hypothesis to guide their data collection and analysis. To better understand and explore the world, scientists’ experimental design is guided by the driving research question. Students will build on what they learn in previous lessons to better understand the driving question. By making connections across lessons, students learn new information by relating it to current knowledge.

Remind students that in Lesson 4, they discussed the differences between predictions and hypotheses. Ask them to review what some of these differences were. Explain that today, they want to develop hypotheses and then design specific experiments around them.
Teacher Content Knowledge

Students often struggle to understand the difference between prediction and hypothesis. Predictions are a guess of what will happen in the future. A hypothesis attempts to explain what will happen next based on known facts, and thus can be used as a starting point for further investigation. A hypothesis can be an explanation to a question that leads to predicted outcomes, which require additional experiments. A hypothesis is often framed as an “if-then” statement but this is actually not sufficient. A hypothesis should have some type of reasoning included in this statement and the reasoning should be based on prior knowledge or experience. In this case, students should make connections to Lesson 4 or other lessons where the impact of the environment on color perception was examined.

When students share their hypothesis, have them explain how it makes connections to each of these three previous lessons. For example, if Strain X had a preference for red pennies under normal lighting in the first penny-pecking experiment (under full-spectrum lighting) and they now know that yellow pennies will appear red under red light, a reasonable hypothesis to test based on this might be something like, “Guppies from Strain X will peck more frequently at yellow pennies under red light than they did under normal (full-spectrum) light because Strain X has a preference for “red” looking pennies.” (the hypothesis can get long in cases like this)

Testing Hypotheses

Once each group has brainstormed a few hypotheses, ask students to develop basic experimental protocols to test these hypotheses.

Remind students that they have a list of available materials at each of these stations listed in their worksheet packet that they can use in their experimental design.

Scientific Practices: Planning and Carrying out investigations

Scientists guide their data collection process based on the questions they are asking. For students, data collection should be based on their prior experiences using similar procedures to specifically test their hypotheses. Students should have an idea of what to change about their procedures to properly collect all relevant data.

Since there will be some pooling and comparison of the penny-pecking data after the experiment, remind students that the groups should aim to be consistent in the penny-pecking protocols they develop.

- How long should each trial take? Did 1 min work well in Lesson 4?
- How should pecks be scored?
Suggest that they use 1-minute test period and use the same scoring system that was developed yesterday because that worked well, and they can minimize variables.

Make certain that when the experiments are approved, each group’s protocol for the penny-pecking activity is consistent between groups as much as possible.

Discuss how the different colors will be distinguished by the counter when the investigation is done. Students need to realize that all the “pennies” will look a similar color under the colored lights.

When not conducting the guppy investigation, students will be participating in a reading activity.

When a group is at the reading station, each person in the group should read one (or two) of the excerpts, after which each participant will report to the group what he/she has read (refer to the discussion page in their handout packet). Students should proceed to develop a synthesis of the reading, composing a synopsis of the excerpts as outlined on their handout.

Tell students that there is a visual deficit known as “achromatopsia,” whereby affected people cannot see any color whatsoever.

**Teacher Pedagogical Knowledge**

Due to time constraints and breadth of information taught in a lesson, learning stations and experimental stations can be set up in the classroom to keep the students consistently engaged. The stations provide information about other applications of the subject matter being taught in the current lesson.

**Teacher Content Knowledge**

A rare genetic color vision disorder in which people are unable to perceive color. A person with complete achromatopia would only see black, white and greys. This disorder is a result of cone cells being unable to properly respond to light. Relying on their rods for visual acuity, achromatics have very low visual acuity and their vision worsens with increasing brightness.

Ask students to imagine how such a condition might affect their everyday lives.

- What sorts of activities might be difficult to pursue with such an impairment?
- How can this be compared to the guppy investigation that they are doing today?

Tell students that Oliver Sacks, a neurologist, wrote a book about this condition called *The Island of the Colorblind*. Students will read sections from The Island of the Colorblind found in their worksheet packet in groups of 3–4 students. Each student should be responsible for 1–2 sections. If students want to read
more, encourage them to do so. If they want to read the whole book, tell them that they can find the book in the local library.

**Main lesson activities**
Students work in groups to plan their investigations based on the penny-pecking protocol and their observations from Lesson 2 (colored candies sorting).

For a large class, students should limit their experiments at each station to 5–10 min, to ensure that every group has time at both the penny-pecking and optics stations; 2) try to minimize overlapping hypotheses to provide different experiments and results for whole-class discussion. For example, if one group is looking at how fish peck at magenta pennies under blue and green light, other groups may want to pursue different color combinations.

### Teacher Pedagogical Knowledge
Data collected from each student group will be shared in a class discussion. If students are all examining different aspects of the same system they will be able to contribute novel data to the class discussion. This will not only encourage student participation in the discussion but also stimulate discussion as to why students chose the experimental design they did and if the different experiments actually properly tested the hypothesis of the group or possibly of another group.

Dim the lights and draw the shades, leaving sufficient ambient light to observe the fish. It is important that the desk lamp serves as the primary light source for fish while they perform the penny-pecking task.

**Penny–Pecking Activity**
Each group of students will need about 10-15 minutes.

Allow students to conduct the same penny-pecking task used in Lesson 4 while illuminating the testing tank with one monochromatic light bulb at a time. A sample protocol might be:

1. Each group member agrees to score a single fish over the course of 60 seconds. Students familiarize themselves with their assigned fish.
2. A single lamp is positioned to illuminate as much of the tank surface as possible.
3. One group member will start the stopwatch/clock when another places the penny-pecking wheel on top of the aquarium water at the beginning of the trial. Care should be taken to keep the wheel in the center of the illumination (it may float a bit at the surface of the tank). As the apparent colors of the pennies will appear to change once they are illuminated by the monochromatic light, the students will need to find a way to distinguish one penny from another.
4. After the clock starts, number of explicit pecks to the “pennies” should be scored as accurately as possible on an individual table like the one below.
5. At the end of the first trial, a desk lamp with a different light bulb should be positioned over the tank. Repeat the procedure using this new light. If time permits, use all three monochromatic light bulbs.

Each group should compile its data in a group table to be submitted to the teacher by the end of class.

<table>
<thead>
<tr>
<th>Lesson 5</th>
<th>My Fish: ______________</th>
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<tr>
<td></td>
<td>Our Strain: ______________</td>
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<table>
<thead>
<tr>
<th></th>
<th>Red</th>
<th>Yellow</th>
<th>Magenta</th>
<th>Blue</th>
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<tbody>
<tr>
<td>Red Penny</td>
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<tr>
<td>Yellow Penny</td>
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<tr>
<td>Magenta Penny</td>
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<td>Blue Penny</td>
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<td>Blue Light</td>
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<td>Red Light</td>
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<tr>
<td>Green Light</td>
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As students carry out the penny-pecking activity, ask the students critical-thinking questions to check their understanding.

- How do pecking preferences of fish in a given strain compare to those observed under nominal lighting conditions seen on previous days?
- On average, how do pecking preferences under different lighting conditions compare across different strains of fish?
- What sorts of natural variations in environmental lighting do different strains of fish encounter?
- Do some fish lose interest in the penny-pecking task over multiple trials? How did this affect your data? If not, how might it affect your data? How could you control for this?

**Teacher Pedagogical Knowledge**

Critical thinking questions teach students to think about their current understanding of topic, to make their thinking more clear. Critical thinking is a great activity to teach a student to think like a scientist! For students to learn well they need to reason with their prior knowledge and their newly learned knowledge to determine a conclusion based on information rather than impressions.

While groups are rotating through the guppy penny-pecking experiment stations, other students will be reading the excerpts from The Island of the Color Blind and discussing the questions in their small group or working on the design of their guppy investigation.
Data Analysis and Class Discussion
This can be saved for a second day if necessary. Have the class reassemble. Begin by asking the class what was the aim of Lesson 5’s penny-pecking task.

- Students should be able to describe how this penny-pecking activity was to extend what was done on the first part of the lesson, by examining how visual perceptions change under different ambient optical conditions (the environment!).

In Lesson 4, students gained expertise expressing their data graphically in pie charts and bar graphs. Tell each student group to use one part of the chalkboard to present the data they recorded in their packet. Explain that the results they present can take the form of data tables, bar graphs, or any other format that clearly expresses their findings. Emphasize to the students that they should label everything they draw on the board clearly.

When the student groups have finished writing their data on the board, invite individual groups to present their data and results to the rest of the class. As the class looks at a particular group’s data, ask the group to describe what they did:

- What hypotheses did they develop? How did they develop them (i.e., how did they synthesize their knowledge from Lessons 2, 3 and the first day of Lesson 4)?
- Do the data support those hypotheses? Why or why not? If not, how could they modify their hypotheses?
- Did they make any other interesting observations during the experiment?
- What trends do they see in their own data?
- Based on casual observation, did students see any differences in the pecking behavior of males vs. females within their strain?
- Did they have any concerns while performing the activity?

Developing a scientific explanation
Using their hypothesis, collected data and scientific knowledge tested, have students develop a scientific explanation. Students need to be reminded that a scientific explanation includes a claim, evidence based on the data and reasoning using the scientific ideas or principles.

After the development and testing of a hypothesis, explain to students that the next step is to evaluate the hypothesis they tested and determine if they need to include a rebuttal in their explanation or revise their explanation.

- Do the data collected support or challenge the hypothesis?
- How do you know?
- How would they revise their hypothesis?
- What might be a next hypothesis that they would be interested in testing based on what they learned from this investigation?
Reinforce the fact that just as much can be learned from an incorrect hypothesis than from a correct one, so the hypotheses they developed do not need to be perfect.

After students have evaluated their hypotheses, tell them that the final step will be revising them.

- If a hypothesis was not supported by the results, how can you modify it to make it fit the conclusions you drew from your data?
- Even if a hypothesis is essentially right, is there any way you can improve upon it?
- Upon what scientific principles is the revision of your hypothesis based? Why did you choose or not choose to modify your hypothesis?

Remind students that all the work they do concerning the development, testing, evaluation and revision of their hypotheses should be recorded on the hypothesis worksheet found in the student materials (U1_L5_StudentPacket_PennyPeckingActivity.docx) for this part of the lesson and will be assigned for homework.

If time permits, discuss the issue of variability in data; otherwise, focus on the questions in the closing of the lesson (listed below) during the closing class discussion.

**Variability in Data (Optional)**
Ask students: What is variability?

**Teacher knowledge (Content):**
There are many ways of measuring variability, but any sort of variability involves measuring how far apart the data within a given set are from one another. Variability within a species can arise from environmental or genetic factors. Environmental (extrinsic) factors can include temperature, sun exposure, food and mate availability, etc. Genetic (intrinsic) factors can arise from susceptibility to disease, natural selection, mutations in the genome, etc.

In this case of the penny-pecking activity, variability can be seen in various ways.

- How different the 3–4 fish of a given strain were in their pecking preferences under a given kind of light
- How differently the fish of a given strain performed collectively under different kinds of lighting
- How different strains of fish performed on the task under a single kind of lighting

What sort of variability they observed in their own strains and across the different strains with respect to penny-pecking under different kinds of overhead lighting.

Conclude this part of the discussion with the following points and questions, and explain that variability within a population will be a theme of Lesson 5. Explain that variability allows one to quantify how different the behavior of the individual is from the population.
Ask the students what accounts for this variability at the biological level. Emphasize as well that there is bound to be some variability from experiment to experiment.

Ask the students what sort of extrinsic factors account for this kind of variability.

Teacher Pedagogical Knowledge
Using overarching themes across lessons, allows for effective learning because this will link prior learning with new information. After having this introduction into variability in the context of the current lesson, students will be more familiar with the new concepts to be discussed in the subsequent lesson.

Conclusion of Lesson
As part of a whole class discussion, ask the students to identify several general conclusions about the differences and similarities between the color perceptions of fish under different ambient lighting conditions, using their own conclusions.

- Does the guppy strain at hand seem to have definitive color preference(s) under different sorts of lighting?
- Based on penny-pecking data from Lesson 4, did the strain have definitive color preferences under white lighting?
- Most importantly: Are the penny-pecking results from Lesson 4 and 5 consistent? In other words, can we understand any differing color preferences today from our knowledge of optics and color perception? For example, if we know that a yellow penny will appear red under red lighting and the group’s data show elevated pecking at the yellow penny under red lighting, this would be consistent with the observation that this strain had a preference for the red penny under normal (white) lighting.
- Do these data reveal anything wholly unexpected? What may account for this?

In preparation for Lesson 6, emphasize that many species (and distinct populations within species) have diverged over time due to the geographical isolation of different populations, whereby the resulting species adapt to the unique conditions inherent to their new environments. Such adaptation manifests at the level of sensory systems as it does any other physiological or anatomical aspect of the organism.

In addition, there is a reading based on Dr. Becky Fuller’s work with questions that bridges Lesson 5 with Lesson 6. There are two versions of this reading (long and short) that can be assigned based on students’ abilities and interests. In the homework, students are asked to first read the excerpt and then analyze two graphs taken from the journal article. Using the graphs, they are asked to determine whether the data support the hypothesis proposed by Dr. Fuller in the text.

Assessments
There are a number of opportunities to assess students understanding of the lesson activities throughout the lesson. Below are several different core activities that could be used as either formative or summative assessments.

Students complete the “Hypothesis Development” and “Experimental Protocol” worksheets as they plan their experiments. This could be used to see what students understand in terms of hypotheses and/or experimental design.

Students use the “Penny-Pecking Station Data Collection” worksheet to record the data they collect throughout the entire lesson. This student sheet has been left mostly blank in order to allow students to decide on how to best record their data; a recommended table for individual and group data collection is found above in the “Group Planning” section.

Student groups collaborate in developing a synopsis of the excerpts they read from The Island of the Colorblind. Each student in the group could submit this group synopsis or alternatively, an individual synopsis could be collected.