Lesson 6: Why do guppies have favorite colors?

I. Overview
In this lesson, students examine how natural and sexual selection can help explain why guppies are attracted to different colors. Students analyze different sensory biases that help a fish survive (such as being able to find different colors of food, or being camouflaged to avoid lurking predators) and how these biases can apply to sexual competition (fish who are brightly colored or have body coloration similar to preferred foods might be more attractive to mates). By playing The Guppy Game students observe how different varieties of fish are adapted to different environments. They can observe male-female differences, and make hypotheses about which habitats favor which traits. By simulating different populations of guppies under different circumstances students observe genetic drift in populations over time. This lesson addresses the crosscutting concept of stability and change in its emphasis on how natural selection and sexual selection can change a population over time.

Connections to the driving question
While playing the guppy game, students learn how the guppies’ attraction to a color impacts survival in a given environment and thus is influenced by the environment. This lesson helps students understand what conditions lead differences in guppies’ vision.

Connections to previous lesson
In the previous lesson, students designed experiments and tested hypotheses about what color guppies see best. If students’ results aligned with Dr. Becky Fuller’s research, they found that guppies had a color preference. Now students will explore the evolutionary mechanisms that have resulted in that color preference.

II. Standards
National Science Education Standards
Science as Inquiry
- Communicate and defend a scientific argument. Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments. 12ASI1.6

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. 12CLS6.2

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. 12CLS6.3

Behavioral biology has implications for humans, as it provides links to psychology, sociology, and anthropology. 12CLS6.4

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
- Mate selection can influence the prevalence of certain traits. 5F/H6b

III. Learning Objectives

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<th>Learning Objective</th>
<th>Assessment Criteria</th>
<th>Location in Lesson</th>
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| Explain how the frequency of a particular trait changes in a population over time. | Explanation can include:  
- Frequency of a trait can change over time if it has a genetic basis and either increases or decreases an organism's ability to reproduce. | Discussion during data analysis collected through playing the game.  
Essay responses under Homework |
| Describe the impact of natural selection on the observed frequency of traits. | Descriptions can include:  
- Natural selection increases the frequency of traits that are advantageous  
- Natural selection decreases the frequency of traits that are not advantageous | Discussion during data analysis collected through playing the game.  
Essay responses under Homework |
<p>| Give examples of natural selection pressures | Examples can include: | Discussion during data analysis collected through |</p>
<table>
<thead>
<tr>
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| Descriptions can include:  
* Sexual selection can increase the frequency of traits such as bright coloration in male guppies if it offers them a reproductive advantage | Descriptions can include:  
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| Give examples of traits that are subjected to sexual selection. | Give examples of traits that are subjected to sexual selection. | Give examples of traits that are subjected to sexual selection. |
| Examples can include:  
* Fin color, brightness | Examples can include:  
* Fin color, brightness | Examples can include:  
* Fin color, brightness |
| Give examples of the impact of different environments on the eventual frequency of traits. | Give examples of the impact of different environments on the eventual frequency of traits. | Give examples of the impact of different environments on the eventual frequency of traits. |
| Examples can include:  
* A murky pond can increase the frequency of sensitivity to bright colors  
* A clear stream can increase the frequency of drab coloration | Examples can include:  
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* A clear stream can increase the frequency of drab coloration | Examples can include:  
* A murky pond can increase the frequency of sensitivity to bright colors  
* A clear stream can increase the frequency of drab coloration |
| Discuss how sensory systems and fish coloration evolve to match different environments. | Discuss how sensory systems and fish coloration evolve to match different environments. | Discuss how sensory systems and fish coloration evolve to match different environments. |
| Responses can include:  
* Sensory systems evolve to make it easier to find food  
* Coloration evolves to make it easier to find a mate | Responses can include:  
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* Coloration evolves to make it easier to find a mate | Responses can include:  
* Sensory systems evolve to make it easier to find food  
* Coloration evolves to make it easier to find a mate |

### IV. Adaptations/Accommodations

Students with special needs might require assistance with some of the tasks of the game. Consider assigning a group leader to assist with rolling the dice and tracking scores if necessary.

### Safety

There are no additional safety concerns, other than those that would be reasonably expected in the science classroom, associated with this lesson.

### V. Timeframe for lesson

#### Day 1

**Opening of Lesson**

- Review previous lessons & introduce Guppy Game – 10 minutes
Main Part of Lesson

- Activity 1: The Guppy Game
  - Learning the rules of the game – 5 minutes
  - Playing one full round of the game – 20 minutes
  - Scoring and Wrap-up – 5 minutes

Day 2

- Activity 1: The Guppy Game (continued)
  - Finishing any outstanding games – 10 minutes
  - Discuss and make predictions about the 6th habitat – 10 minutes
  - Playing the last habitat – 5 minutes
  - Scoring and wrap-up – 5 minutes

Conclusion of Lesson

- Discussion of outcomes – 10 minutes

VI. Advance prep and materials

Students should be put into groups of four. If the groups are smaller than four, some students will play two guppy cards.

Activity 1: The Guppy Game

Materials:
Each group will need:
- One six-sided die
- One set of guppy and habitat cards, printed in color and double-sided on cardstock (U1_L6_Cards_GuppyGameCardSet.pdf)
- One scorecard per student, printed in black and white (U1_L6_Cards_Scorecards.pdf)
- One quick rules document, printed in color (U1_L6_StudentSheet_QuickRules.pdf)

Preparation:
- Print and cut enough card sets and Quick Rules documents. To make long-lasting card sets, laminate the guppy and habitat card set before cutting. You can print additional scorecards for every class as necessary.
- Know how to play the game.
- Know the game relates to evolution.

Homework and Assessments

Materials
- Three essay prompts and four assessment questions are included at the end of the lesson.

VII. Resources and references
Teacher resources

- Background knowledge for teachers, U1_L5_TeacherResource_BackgroundKnowledge.docx

References


Citations

Images used in the Guppy Game

VIII. Lesson Implementation

Opening of Lesson:
Review briefly from the previous lessons by asking students the driving question,

- "Why do guppies have favorite colors?"
  - Students should be able to provide some answers based on previous lessons.

<table>
<thead>
<tr>
<th>Teacher Pedagogical Knowledge</th>
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<tbody>
<tr>
<td>Using a driving question provides students with a common theme to understand the lesson content. Driving questions can also be valuable for connecting a lesson to previous and future lessons. Especially in science, driving questions help motivate students’ curiosity about a topic.</td>
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</table>

Continue this discussion by asking

- Is this favorite color limited to food preference or are there other reasons why fish might have a color preference?
  - Students might struggle to answer this question because all of the previous lessons have focused on color of food preference, however students should be encouraged to think about this question and pose possible reasons why fish might have other reasons for color preferences.

If students continue to struggle, ask:

- Why are males and females different colors?
- Are there any other species where the males are more colorful than females? (e.g. peacocks)
- Where do guppies live in the wild?
- What eats guppies?

This discussion should continue with questions about what guppy would survive best in a habitat with lots of predators. Additional questions that can be used to help guide the discussion include:

- How would color impact the survival of the fish?
- How have the fish that they have observed differed?
- Would these different colors impact how a fish might survive?
- How would a brightly colored guppies or drably colored fish survive?
- What would happen over a few hundred generations?
Teacher Pedagogical Knowledge

Using student responses to address common misconceptions is a useful way to integrate assessment into everyday teaching. Students enter the science classroom with ideas about how the world works. Students should be made aware of their potential misconceptions to help them clarify their thinking about a concept.

These questions will focus students on ideas of natural selection and evolution. Make certain that students’ responses are recorded since they will be used in the wrap-up discussion. If possible, record the responses to these question and the ones below on the board or large piece of paper.

After this opening discussion, have the students imagine a habitat with very murky water, so murky that it would be difficult to see in. Ask the students:

- What would happen to the guppies’ ability to see colors?
- What would happen over a few hundred generations to fish in these types of waters?

Student Misconceptions

It is common for students to think that different environments cause individuals to develop new traits in order to survive (Bishop & Anderson, 1990). Help students overcome this misconception by focusing on changes in the prevalence of a trait that happen over long periods of time.

Now have the students imagine a habitat with very clear water, ask the students how would their predictions change.

- What would happen to the guppies’ coloration and their ability to see colors?
- What would happen over a few hundred generations to fish in these types of waters?

Tell the students that they will be playing a game that will allow them to test their predictions to these questions.

Main Part of the Lesson

Activity 1: Guppy Game

Introduce the game by first explaining the rules. Hand out the quick rule sheet so that each student has a rule sheet. Briefly go over the rules of the game by using an example fish. Have students look at the rules of the games (covered in the provided student documents).
The Guppy Game has been designed to be a game that will motivate student learning. The game is designed to parse the subtle evolutionary algorithm into a more easily understandable package. The key to presenting this lesson is to start with a discussion of evolutionary forces by posing a series of questions about different habitats and species found in the introduction to the activity.

Model what happens to the fish after a roll of the dice for both survival and reproduction.

Make certain that students understand that the guppies’ defining attribute (brightness for males and sensory bias for females) is sometimes advantageous and sometimes disadvantageous. It’s advantageous for a male guppy to be bright when he’s trying to impress a potential mate, but disadvantageous when he’s hiding from predators.

Similarly, it’s advantageous for a female to have a strong preference for bright colors when she’s searching for food (it makes her choose high-energy, brightly colored foods like fruit), but it’s not helpful when she’s choosing a mate (she’s very “picky” and may pass on an opportunity to mate with males who are too drably colored).

After the rules are explained, check to see if the students can explain what it means to roll over/under the brightness/bias? Ask the students:

- Is being bright/strongly biased advantageous or disadvantageous?

Additional questions that can be used to check student understanding include:

- During the “survival” phase, why do males have to roll under their brightness?
- During the “mating” phase should females roll under or over their preference?
- Is it advantageous to be bright? Is it advantageous to have a strong color bias?

After going through the rule sheet, place students in groups of 4–5 so that they can play the game. Hand out enough fish cards so that there is a male and female of each species in the group. It might be necessary for students to have multiple fish cards so that all fish types are represented. Each group of students should have 1–2 dice in order to play the game.

Have students first choose a fish (male or female, bright or drab), and then a habitat (it’s best to start with the basic one, Practice Pond).
Teacher Pedagogical Knowledge
It is important for struggling students to go from simple to complex environments in the game. Gradually increasing complexity provides scaffolding for students to learn the concepts being addressed in the game.

Allow students to roll for **survival** and **reproduction** using the practice pond.

- In the **survival** roll, it’s best to be drably colored (if you are male) and have a strong sensory bias (if you are female). This helps the males hide, and the females find food.
  - To reflect this, males need to roll *equal or over* their brightness (more difficult for higher brightness).
  - Females must roll *equal or under* their bias (more difficult for lower bias) to successfully find enough food to survive and generate an egg clutch.
- However, for **reproduction** the numbers are flipped, and students must roll in the opposite direction:
  - *Equal or under* for males, and
  - *Equal or over* for females.

Gaining an intuition to this mechanic will greatly smooth future play.

After students have completed one practice round, review to see if students are understand the direction the game is going in. Do this by asking students

- Which guppy will be successful in which habitats?
- What will happen when the two strains of guppy mix?
  - Make certain students explain their responses

Allow students to continue playing the game to see if their predictions are accurate. Each different habitat will modify these rules slightly, either by changing the number of times players roll for each of these phases, or by changing the brightness numbers either up or down. Allow students to play through each of the habitats and keep score for the fish they selected. Each fish that survives the **survival** phase scores one point. Each fish that successfully **reproduces** scores 2 additional points for a total of 3.

Students may not have time in a single day to play through all of the habitats. Each habitat takes about 5 minutes to play through and properly score, and there are 6 in total. Two solutions are to spread the activity over the course of two days or simply to reduce the number of habitats to about four.
Scientific Practices: Obtaining, evaluating, and communicating information

Consider having students construct their own data tables, or walk them through the process so that they can become proficient in this skill. Doing so will enable students to communicate their understanding of the data generated by playing the game.

Collecting class data

Post a table on the board so that each group can fill in each cell with the aggregate scores from their group (see example table below where example scores have been filled in for practice pond for one group). This will give the class a feel for which guppies are best adapted for which habitats. Use this table for a discussion about which guppies are best adapted for which habitats.

Class-wide scoring involves filling in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Domestic Guppy (5F)</th>
<th>Domestic Guppy (5M)</th>
<th>Wild Guppy (2F)</th>
<th>Wild Guppy (2M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice Pond</td>
<td>25*</td>
<td>17</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>Amazon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish Tank</td>
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<tr>
<td>Murky Pond</td>
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<tr>
<td>Clear Stream</td>
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<tr>
<td>Quiet Brook</td>
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</table>

Example scores are provided as a sample of how the table will be filled in. Each group should fill in the class table using their aggregate scores.

Teacher Pedagogical Content Knowledge

If the patterns for which fish does best in each environment are unclear, collapse the data so there is a Domestic Guppy column and a Wild Guppy column by adding the scores for the males and the females together. By doing this, the trends become clearer.

Conclusion of Lesson

After the students have played a complete game and posted the aggregate scores from their group, have the class come back for a critical discussion about what they saw happen through the game.
Scientific Practices: Constructing explanations

It is important that the scores are discussed. These scores should be treated as the outcome or data that need to be integrated into students’ explanations.

Whole class discussion about understanding what the scoring means:

After the class data table has been filled in, discuss which guppies ended up being most successful in which habitats as a group. Some example questions might be:

- Where did the male domestic guppy do best? Where did he do worst?
- Was there any guppy that did well everywhere?
- What kind of guppies did best in the Amazon?
- Was your prediction about the Quiet Brook correct?

Using the data that has been generated, refer back to the predictions that students made at the start of the class. Ask the students if they had predicted accurately or not about the colors and habitats.

Refer back to the responses that were recorded on the board or paper in order to check what students say.

- If students had predicted correctly, ask them why this is the case.
- If they had predicted incorrectly, ask students if they can now begin to explain why they predicted incorrectly.

Students now have data to support their claims and can begin to develop a scientific explanation that links what they have learned throughout the unit with natural selection and evolution. The scores or data allow the students to develop a scientific explanation to the questions that were asked.

Have students rethink the questions and how they would respond. Wherever outcomes do not support predictions, ask why the data turned out differently than they originally anticipated.

Teacher Pedagogical Content Knowledge

A scientific explanation should include a claim, evidence, and reasoning (and a rebuttal if appropriate). The evidence is the data students use to support their claim. In this case, the data are from the data tables created as a result of the game. The reasoning is the scientific principle(s) that connect the evidence and the claim to the scientific knowledge being developed by the students throughout the unit.

Expected (but not required) Results
• Brightly colored male guppies (5s) will perform best in the fish tank and the muddy pond where they are less vulnerable to predators.
• Drab male guppies (2s) will do best in the clear stream and Amazon where predators are more prevalent.
• Female guppies with strong color biases (5s) will do best in the muddy pond where their strong bias makes them more likely to find food.
• Female guppies with weak color biases (2s) will do best in the fish tank or clear stream, where food is readily available.

Using the class data/score card, ask the students:

• Did anything not turn out as expected? Why?
• Which guppy got the largest benefit from low predators, the one who was already good at avoiding them or the one who was poor at avoiding them?
• Which guppy would benefit the most from increased chances to mate?

The “ideal” guppies
Use this discussion to lead into what makes an average ideal guppy. Ask the students what makes an “ideal” guppy.

• Is the ideal guppy the same for all habitats?

After you have discussed these interpretations, it’s important to point out that we can be more accurate about the ideal guppy in each habitat. We started with two different varieties, but these guppies can interbreed. Have students make some predictions about how the average bias or brightness will change in each of these environments. In order to help students, ask students questions like:

• What do you think the ideal brightness would be in the murky pond? For environment X?

Once students have some predictions on which brightness and bias is “ideal” for each environment, point out that they have the data to answer this question by finding the average brightness and average bias for each environment.

Scientific Practices: Using mathematics and computational thinking
The Guppy Game is a model that is based on mathematical principles. Doing math in science class conveys to students how math is valuable to scientists’ work.

Calculating the “ideal” guppy for each habitat is just a matter of applying the below formula for each habitat:
\[
\frac{(Number \ of \ Wild \ Guppies) \times 2 \ + \ (Number \ of \ Domestic \ Guppies) \times 5}{(Number \ of \ Wild \ Guppies \ + \ Number \ of \ Domestic \ Guppies)}
\]

For example, using the data in the table above, practice pond would be:

- Female guppy color preference: \( \frac{(25 \times 5 + 15 \times 2)}{(25 + 15)} = 3.875 \)
- Male guppy brightness: \( \frac{(17 \times 5 + 21 \times 2)}{(17 + 21)} = 3.34 \)

This will give a set of different guppies, which are likely the dominant guppies in that environment. After all, the game started with two gene pools by introducing the wild and domestic guppies and over time, through natural and sexual selection pressures (as modeled by the game), they settled out automatically to the optimum guppy species for that habitat.

However, it may be valuable to ask the students to come up with the formula. Opportunities to use mathematics skills to answer scientific questions are often few and far between!

**Scientific Practices: Engaging in argument from evidence**

Students should integrate data from the Guppy Game to support any claims they make in order to answer the following discussion questions. Remind students that an important practice that scientists engage in is using evidence in their arguments.

Ask students why this “ideal” guppy matters.

- Students should be able to explain that the average guppy is a result of the successful gene pool created from the two extreme guppies. Their genes were mixed together in the environment to automatically find the best solutions to color bias and brightness problems.

Make certain that students reference specific data to support their claims. Having a student say “Brighter guppies did better in the murky pond because it was murky” reflects circular reasoning and is not sufficient. Push students to support their claim through the data that they have and to provide a scientific reason as to why the data support their claim.

Through this discussion, it is important that students understand that the guppies in the final environment are the result of an evolutionary process, which took place *in their genes* and not at the level of individual guppies.

- Point out that there might be a few cases of lucky individuals (a brightly colored male who survived in the Amazon and reproduced for example), but that this doesn’t necessarily have a very large impact on the overall gene pool at the end.

Ask students to describe a change to one of these habitats that would change our results.
Possible examples might be:

- A new dam is built on the river that keeps all the predators out of the guppy habitat.
- A new species of predator moves in which doesn’t like to eat brightly colored guppies.

This discussion can set up the assessment questions and homework items. To do this, ask the students to think about how what they just learned about guppies could be applied to other situations. Have the students brainstorm ideas of organisms that might share the characteristics that they saw with guppies but live in different environments or be different organisms. Tell the students that they will read about several examples and answer questions based on what they learned today but apply it to new situations as homework.

Reading connected to Lesson 6: If Lesson 7 is being done in sequence, please make certain to briefly review expectations for reading U1_L7_Reading_EvolutionOfColorVision. This reading is provided under Lesson 7 materials.

**Supplemental Activity**
The following online lab is an ideal jumping off place for students interested in the evolutionary pressures experienced by guppies. Be sensitive to the fact that not all students have Internet access, but the benefit of this online resource is just too large to ignore. It can be printed for students who lack access. http://www.pbs.org/wgbh/evolution/sex/guppy/low_bandwidth.html

<table>
<thead>
<tr>
<th>Scientific Practices: Constructing explanations</th>
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<tbody>
<tr>
<td>Students should link evidence and models to their explanations just as scientists connect their explanations to evidence and models.</td>
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**Assessments**
The following are three possible essays prompts that would be used as homework assignments or as part of the unit assessment.

**Essay 1**
Henry David Thoreau wrote the following description of Walden Pond during the time he lived on its banks:

“The scenery of Walden is on a humble scale, and, though very beautiful, does not approach to grandeur, nor can it much concern one who has not long frequented it or lived by its shore; yet this pond is so remarkable for its depth and purity as to merit a particular description. It is a clear and deep green well, half a mile long and a mile and three quarters in circumference, and contains about sixty-one and a half acres; a perennial spring in the midst of pine and oak woods, without any visible inlet or outlet except by the clouds and evaporation...”

In addition you know the following about the pond:
1. There are no natural predators that are adapted to eat guppies, though there are some larger fish, which might eat an occasional guppy opportunistically.
2. There are no naturally occurring brightly colored foods in the red-orange spectrum. However, there are patches of sugar-rich blueberries which live along the banks of Walden.
3. Walden lacks good places for fry and pregnant females to hide, it is very clear.

In a one-page, 3–4 paragraph essay describe a variety of guppy which would be adapted to live in Walden pond. Be sure you mention both how female’s color bias could change to adapt to the unique habitat, and how male’s coloration would change. You should also speculate as to how the native fish might change in response to the introduced guppies.

**Essay 2**
In a small stream in Trinidad live a drably colored, high-sensory-bias variety of guppies and several species of voracious predators. Because predation is so heavy, the guppies have evolved many strategies for hiding from the predators and both males and females are a dull brownish color. Food is so scarce in this stream that only females with the strongest biases toward reds and oranges can find enough food to grow a clutch of eggs. One day, a farmer decides to build a dam on the stream to irrigate some crops. This creates a pool in the stream, and prevents predators from swimming upstream to the pool. In addition, runoff from the farm causes the pool to be much murkier than before. In a 1-page, double spaced, 3–4 paragraph essay, discuss how the coloration and sensory biases of the guppies that live in this changed pool environment are likely to change over the next few generations. Be sure to discuss how quickly this change will occur and what forces will drive it. What will the guppies look like in a dozen generations? In a hundred generations?

**Essay 3**
There is a variety of guppy in which males have bright red and orange scales, and females are strongly attracted to red and orange colors. Female guppies show little to no interest in blue dots. Given what you know about how these traits evolve, write a 1-page, double spaced, 3–4 paragraph essay which describes the habitat that these guppies evolved in. Be sure to specify the water conditions, amount of predation, prevalence of and types of food, and how these features all came together to create the guppies described above.

**Additional Assessments**
Some additional useful topics that could be used as assessment prompts are included below. These questions could be used as pre-assessments or as post.

If used as pre-assessment, the answers will provide useful information about what students know prior to instruction. If used after in place of the proposed essay questions, these questions will provide a near transfer context that can be used to measure what students learned.

Depending on the purpose, these questions could be answered individually or by groups of students.
1. Why are male peacocks so brightly colored? Why aren’t the females so brightly colored? 
   This question gets at the idea of the equilibrium between natural selection pressures, like finding food and avoiding predators, and sexual selection forces like mating displays and coloration. This is a fairly simple introduction since it’s fairly easy to see how the drab female coloration is more driven by avoiding predators, while the bright males are driven to be more impressive to females.

2. There are many species of brightly colored reef fish in the oceans. What limits how colorful they can be? Why aren’t they bright white with rainbow speckles? What’s the limiting factor? 
   This question gets at evolutionary counter pressures, like predation, which prevent runaway sexual selection from creating arbitrarily colorful fish.

3. Why is it usually the male who is brightly colored? Why don’t females need to impress mates? 
   An intriguing question for getting at underlying knowledge. There are several reasons for the above; males are typically more common, and more able to mate with multiple females, making inter-male competition more severe than inter-female competition. In addition, because of the above factors, males are less critical and some can be lost to predation without upsetting the fecundity of the species.

4. Imagine we introduced a new kind of gigantic predator onto the African savanna which could catch and kill adult elephants. What would happen to the African Elephants? 
   This question has no right answer, but it’s a good way to get students synthesizing the ideas captured by the game. It’s a good time to impress upon the students that there are often many interesting hypotheses about evolution, but that all of them require considerable testing.