HOW TO USE THIS RESOURCE

The images for this resource show stickleback fish, some with spines and some without spines, which can serve as phenomena to explore the key concepts described below.

The pedagogical practice of using phenomena to provide a context for understanding science concepts and topics is an implementation practice supported by the Next Generation Science Standards (NGSS). Phenomena are observable occurrences that students can use to generate science questions for further investigation or to design solutions to problems that drive learning. In this way, phenomena connect learning with what is happening in the world while providing students with the opportunity to apply knowledge while they are building it.

The "Implementation Suggestions" and "Teaching Tips" sections provide options for incorporating the images into a curriculum or unit of study and can be modified to use as a standalone activity or to supplement an existing lesson. The "Student Handout" includes reproductions of the images and the "Background Information" section.

Additional information related to pedagogy and implementation can be found on this resource's webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- Dramatic changes in traits can occur through mutations in a gene regulatory region.
- Different environments can provide different selective pressures on an organism's morphology. In the stickleback fish, pelvic spines provide a selective advantage in environments with large predatory fish but are a liability in environments with dragonfly larvae.
- The evolution of anatomical traits can be studied by carefully measuring and comparing related populations living in different habitats, by comparing the DNA of individuals with similar and different traits, and by analyzing the same trait in related species found in the fossil record. All three approaches have been used to study the evolution of pelvic reduction in the stickleback fish.

BACKGROUND INFORMATION

Threespine stickleback fish, sometimes called just **stickleback fish**, are a type of small fish found in the ocean, freshwater lakes, and some other bodies of water. Until about 10,000 years ago, most stickleback fish lived in the ocean. But when the last ice age ended, the melting ice sheets created many new lakes. Some stickleback fish from the ocean swam into these lakes. Later, connections between the ocean and some lakes dried up. As a result, the stickleback populations in some lakes were trapped there for thousands of years.

Over time, certain traits became less common among the stickleback populations in lakes compared to the populations in the ocean. For example, most stickleback fish in the ocean have pointed, bony structures called **pelvic spines** on their underside surface. The pelvic spines make it hard for large predators to swallow stickleback fish. However, stickleback fish in some lakes lack pelvic spines.

The presence of pelvic spines, like many physical features, is determined by genetics. In stickleback fish, a gene called ***Pitx1*** controls the development of the pelvis and pelvic spines. *Pitx1* is not active in the **pelvic area**, where the pelvis and pelvic spines would develop, in lake stickleback fish without pelvic spines. However, *Pitx1* is still

active in other areas, where it controls the development of other body structures in *all* stickleback fish. This finding has led scientists to wonder how a gene can affect structures in one area of the body but not in others.

The images show several stickleback specimens. The pelvic area is circled in each image.

- Images **A, B, and C** show modern-day stickleback fish from a population in a lake. This population has considerable variation for pelvis-related traits. The pelvic structures have been stained red using a special dye. Each image shows a side view and an underside view of the same fish.
  - Image A is of a fish with a complete pelvis and pelvic spines.
  - Image B is of a fish with a reduced pelvis and no pelvic spines.
  - image C is of a fish with no pelvis or pelvic spines.
- Images **D** and **E** show fossils of two different stickleback fish that lived thousands of years ago.

IMPLEMENTATION SUGGESTIONS

The following suggestions outline several options for incorporating the images into a unit of study as phenomena:

Engagement, establishing prior knowledge, and providing context:

- Begin the lesson by telling students that they will be examining a series of images of stickleback fish, which are a small fish species found in the ocean, freshwater lakes, and some other bodies of water.
- Show students Image A, which has two views of the same stickleback fish. Ask students to make observations using the sentence stems "I notice…", "It reminds me of…", and "I wonder…"
- Use a think-pair-share protocol to have students share their observations and questions about the images. Record class observations, noting when students make similar observations and drawing attention to the range of student-generated questions.
  - Students may observe that:
    - The fish appears to be relatively small (about 7 cm long).
    - The fish has various tissues intact.
    - The fish has fins on its back, tail, and underside. Some of the fins appear to be soft and others hard (like spines).
    - There is a circle around part of the fish's underside. Inside the circle are structures (spines) colored red.
    - There are labels with numbers and writing next to the fish.
  - Students may wonder:
    - What is the function of the spines on the underside of the fish?
    - Where do fish like this live?
    - What do they eat?
    - What predators are found in their environments?
    - What do the labels around the fish mean?
- Show students Image B, which has two views of a second stickleback fish, and Image C, which has two views of a third stickleback fish. Ask students to compare these images with Image A, using the sentence stems "I notice…", "It reminds me of…", and "I wonder…"
- Use a think-pair-share protocol to have students share their observations and questions about the images. Record class observations, noting when students make similar observations and drawing attention to the range of student-generated questions.
  - Students may notice:
    - All the fish appear to be similar in size.

        - All the fish appear to be similar in appearance, except for the circled areas on their undersides. These areas may have some structures that are stained red, either spines or red spots. The first fish (A) has spines, the second fish (B) has red spots but no spines, and the third fish (C) has no red spots or spines.
        - Each fish is labeled with a different number, but they all have the same label at the top: Morvoro Lake, MABO9-15.
    - Students may wonder:
        - Why do some of the fish have red spots or spines?
        - Do the labels mean that all the fish came from the same lake? If so, why are fish both with and without spines living in the same lake?
        - Did this fish species originally have these spines and then "lost" them? Or did they originally not have these spines and then "grew" (developed or evolved) them?
- Watch the video clip "Stickleback Fish Environment" through 0:55, which provides an introduction to stickleback fish that live in freshwater lakes.
- Ask students to generate a list of ways, including both physical characteristics and behaviors, that stickleback fish could avoid being eaten by predators, such as a larger fish or a dragonfly larva.
    - Student examples could include protective structures (such as spines, spikes, or "armor"), camouflage, being able to swim quickly to avoid predators, being active at times of day when predators are absent, etc.
- Watch the rest of the video clip and ask students to note how stickleback fish in freshwater lakes may avoid predation.
- Transition to the next set of images by telling students they'll be examining pictures of stickleback fossils. These fossils are of a species that lived a long time ago but that is similar to the one in Images A, B, and C.
    - The images of the fossils are lateral (side view) images. Note that the spines may look different and could be harder to identify in the fossil images.
    - Students may ask why there are no ventral (underside view) images for the fossils. Note that ventral images are easy to get for modern specimens but not for fossils.
- Show students Images D and E, which each show a different fossilized stickleback fish. Ask students to compare these images with Images A, B, and C using the sentence stems "I notice…", "It reminds me of…", and "I wonder…"
- Use a think-pair-share protocol to have students share their observations and questions about the images. Record class observations, noting when students make similar observations and drawing attention to the range of student-generated questions.
    - Students may observe that:
        - The fossils preserved bones but not skin, organs, or other soft tissues.
        - One of the fossilized fish (D), which has spines on its underside, appears to be larger than the other (E), which does not.
        - There are similarities between the modern-day and fossilized fish. For example, some stickleback fish have spines on their undersides and others do not.
    - Students may ask:
        - How old are the fossilized fish compared to the modern-day fish?
        - Why do some of these fish have spines and others do not? What do the fish with spines use their spines for?
        - What are the spines made of?
        - How did some fish "lose" their spines? It may be important to have students consider how that loss can occur on two timescales: loss during an individual fish's lifetime (e.g., mutation, developmental abnormality, injury) and loss of that trait in a population over evolutionary time.

- Have students read the "Background Information" for the images.
- Transition to the "Exploration/Investigation" section by telling students that they'll be investigating some of their initial questions about stickleback fish.

Exploration/Investigation:

- Watch the short film *The Making of the Fittest: Evolving Switches, Evolving Bodies*, which explores how mutations in gene regulatory regions have resulted in major changes in the anatomy of freshwater populations of stickleback fish.
  - If regulation of gene expression is outside the scope of your course, emphasize to students which key concepts to focus on while watching the film (e.g., multiple lines of evidence for evolution, how scientists determine gene function, etc.).
  - Discussion questions with relevant time stamps are available as part of the associated film activity.
  - The film is also available as an interactive assessment with embedded questions at automatic pause points. This version of the film may be useful in distance-learning classes for students to check their own understanding of the concepts presented.
  - It may be helpful to pause the film at 5:55, before it shows how researchers determined there was a mutation in the gene "switch" of the *Pitx1* gene, and have students complete one or more of the activities below before seeing the rest of the film.
- Have students complete the *Stickleback Evolution Virtual Lab*, which explores how both modern-day stickleback fish and fossil specimens are used to study evolutionary processes. In this lab, students learn and apply techniques for analyzing the forms and structures of stickleback pelvic spines. The lab includes three modules in which students collect and analyze data using photographs of "living" fish specimens and fossils.
  - The accompanying "Student Handouts" provide structure and guidance as students perform the tutorials, experiments, and quizzes in the lab. The only difference between the "Basic" and "Advanced" versions of the handout is that the former does not include the parts of the lab with chi-square analyses.
  - To save time, consider skipping the tutorials (or showing them as a class demo), having students complete just modules 1 and 2 (which focus on analyzing living and fossil specimens respectively), or using a jigsaw approach for the modules.
- Complete the hands-on activity "Using Genetic Crosses to Analyze a Stickleback Trait," in which students apply the principles of Mendelian genetics to analyze the results of genetic crosses between stickleback fish with different traits. In this activity, students make predictions using Punnett squares, sort photos of actual research specimens (the F1 and F2 cards) to collect data, then analyze their data along with additional data from the scientific literature.
  - The activity can be adapted for online classes by having students annotate the F1 and F2 "Stickleback Cards" PDFs to note the presence or absence of pelvic spines. It may be helpful to split the class into five groups (one for each page of the F2 PDF), have each group examine the cards on their assigned page, and then combine the results.
  - Depending on student level, students may need additional scaffolding to complete and analyze the ratio calculations in the activity.
  - The optional "Extension Activity" and "Enrichment Activities" sections at the end of the "Student Handout" include doing a chi-square analysis to determine the significance of the results and completing additional Punnett squares for a variety of genetic crosses. It may be appropriate to skip or condense these sections, depending on timing and student level.

Assessment:

- Return to the questions that students generated when they first saw the images. As a class, discuss which questions were addressed by the "Exploration/Investigation" activities and which are still unanswered.

  - For example, students should now be able to address the following question: "Why do some stickleback fish have spines and others do not?"
- Assess student understanding of how stickleback populations evolved using the "Student Quiz" from the "Activity for *Evolving Switches, Evolving Bodies*."
  - Questions 1–6 are appropriate for intro and advanced high school biology. Question 6 shows other fossilized stickleback fish with additional information.
  - Questions 7 and 8 are more appropriate for upper-level students.
- Have students examine the published scientific figure from the Data Point "Pelvic Evolution in Sticklebacks," which is from a study that used SNP genotyping to identify the mutations that result in morphological differences in stickleback fish. The associated discussion questions can be used to generate assessments using the figure, depending on student familiarity with SNP data.

Extension:

- Extend student learning about gene regulation in stickleback fish by having them complete the activity "Modeling the Regulatory Switches of the *Pitx1* Gene in Stickleback Fish." In this activity, students interpret molecular diagrams and build physical models of eukaryotic gene regulation to explore why the *Pitx1* gene is expressed in some tissues but not others.
  - To adapt this activity for distance learning, students can build their models using household materials (such as markers, string, and various small objects) or construct digital models using any software that can generate shapes (such as PowerPoint, Google Slides, or Miro).
  - Depending on class timing, it may be helpful to divide portions of the activity among student groups rather than having all students complete all portions.
    - For example, consider dividing Questions 4–10 in Part 2 among student groups, then having groups compare their responses.
    - Alternatively, you could use some questions as formative assessments rather than having students do them during the activity.
  - Students often have the misconception that plants either do not have DNA or have genetics that are fundamentally different from those of animals. Help students transfer their knowledge of gene regulation in stickleback fish to a plant example with the playlist "Teaching Gene Regulation Using Corn and Stickleback Fish." The first three resources (a video and two activities) ask students to investigate another genetic mystery: why corn looks so different from its wild antecedent, teosinte.

TEACHING TIPS

- Present students with the images first, before they read the background information.
- Encourage students to draw upon their prior experiences and knowledge to interpret the image and generate questions.
- Provide opportunities for students to explore outside sources to promote their independent explorations and discussions.
- Background information may be edited to support student proficiency, course sequence, etc.
- The images may be projected in lieu of handouts.
- Printed images can be laminated for use in multiple classes.
- Pair or group students to work through one or more of the implementation suggestions.

CREDITS

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