"Shell Shocked" – Instructor's Guide

Overview: Students study the elaborately whorled, sculpted, and ornamented seashells of gastropods not as objects of beauty, but as artifacts born of a cruel evolutionary tradeoff: They are costly to build and carry around, yet essential for survival in a dangerous ocean. The high school version introduces the concept of an evolutionary arms race (coevolution) and reinforces the Darwinian principle of "form follows function." The middle school version emphasizes the concepts of animal adaptation and predator avoidance. Both versions center on the fossil record.

Grades: 7-12. The high school version employs evolutionary concepts, while the middle school version uses the language of animal adaptations but not evolution. Also adaptable for upper elementary.

Subjects: Earth science, biology, paleontology, evolutionary science, predator-prey ecology

Approach: The lesson plies an "explore-before-explain" pedagogy, with a dose of inquiry and data analysis. It opens with a short, simple laboratory in which students evaluate seashells for their ability to deter predators. Next, they watch select segments from "The Survival Game" episode of *The Shape of Life* video series (free online), which develop a more formal understanding of predator-prey "arms races" (a case of coevolution) and highlight the research of the famous paleontologist Geerat Vermeij. Finally, students examine a handful of Vermeij's graphs showing 500 million years of actual seashell fossil data. They use their new insights about shell design to interpret fossil trends as evidence of a relentless coevolutionary arms race between molluscs and shell-breaking predators.

Logistics: 45-60 minutes. 2-3 students per team.

Materials: An assortment of 8 to 12 gastropod seashells. Try to get a variety of forms. Good specimens include whelks, conchs, cowries, olives, augurs, murexes, turbans, etc. You only need one of each species, as each team can analyze one shell at a time and then exchange it for a new one.

Suggested instructional sequence:

1. Distribute the handout "Shell Shocked" (either the high school or middle school version) and have students read the front page, then carry out the lab activity on the second page. Place seashells in a common area with species labels. Each team is to take only one shell at a time, analyze it and record ratings in the data table, and then exchange it for a new shell. Alternatively you can simply have students pass each specimen from one team to the next. Continue until all teams have evaluated all or most of the species. (Note: Students should wait until after viewing the relevant *Shape of Life* segments – see below – before beginning the data analysis exercise on pages 3-4.)

2. After the lab activity, spend a few minutes reviewing results through whole class discussion. Then tell your class that the study of anti-predator seashell designs has been the lifelong obsession of renowned paleontologist Geerat Vermeij of the University of California at Davis. Then show select video segments from The Shape of Life website (http://www.shapeoflife.org/):

   - Essential viewing: "Geerat Vermeij, Evolutionary Biologist: Reading A Shell's Story" (7.5 min; in the "Scientists" hub). This segment nicely develops the theme of predator-prey co-adaptations and "arms races," and sets up the student data analysis exercise to follow.

   - Recommended: "Mollusc Animation: Shell Repair" (1.5 min; in the "Animation" hub). A quick piece on how molluscs manufacture and repair their shells.

3. Now have students carry out the data analysis exercise on pages 3-4 of "Shell Shocked," which asks students to interpret 4 graphs drawn from Vermeij's own research. Afterwards go over their answers via whole class discussion. See below for an interpretation of Vermeij's data.
4. Closure: Show *The Shape of Life* segment "Molluscs: The Survival Game" (15 min; in the "Phyla" hub) – an excellent overview of the biology, behavior, and body forms of the main molluscan taxa (gastropods, bivalves, and cephalopods) which reinforces the theme of predator-prey co-adaptations and "arms races." You may wish to couple this segment with formal instruction on Phylum Mollusca, depending on your own course objectives.

Post-lab Discussion: Interpretation of Vermeij's Data in "Shell-Shocked"

The first graph shows that predators with an ability to break shells first appeared about 450 ma. Since then their numbers have risen, right up to the modern day. Among predators, then, natural selection is clearly favoring traits that enable shell-breaking, and thus those traits are increasing in frequency. Meanwhile, as the other three graphs show, soft-bodied molluscs are evolving ever better defenses against those shell-breakers. Many gastropods foil the new predators by developing high spires or narrow apertures with thickened margins. Bivalves and others escape by heading underground or boring into rocks. And cephalopods reinforced their shells by coiling them or "sculpturing" them with ribs, bumps, knobs, and spines. At the same time, snails with a "weak shell design" have steadily diminished in number. Among prey, then, natural selection is clearly increasing the frequency of traits that protect against shell-breaking predators, while weeding out traits that do not.

- A side question to explore with students: Why aren't "weak designs" completely weeded out? Probably because there is a cost to making bigger, heavier, more spiny shells. They take lots of calories and chemicals to build. Those are resources that could instead be invested in the production of offspring. Also, such shells probably slow an animal down, forcing it to burn more calories during foraging and diminishing the amount of calories collected for survival and reproduction. It's an evolutionary tradeoff: There are both benefits and drawbacks to the trait.

Coevolution occurs when two different groups of organisms mutually influence each other's traits. They perpetually adapt to one another. In terms of natural selection, each acts as a "selective pressure" upon the other. It is easy to see here that molluscs have been evolving in response to the ever increasing threat of shell-breakers, but coevolution implies that the predators are evolving in response to the prey, too. Do we have evidence of this? Perhaps. Since shell-breakers are increasing in abundance and diversity (number of different taxa), it is clear that shell-breaking continues to be a successful way to make a living. So presumably, even as the prey are developing better and better defenses, the predators are successfully evolving new and different ways around those defenses. It's a never-ending arms race, still going on today!

However, Vermeij himself has argued that this coevolution is asymmetrical: Prey are pressured to evolve specialized adaptations to predators more strongly than predators are pressured to specialize to their prey. Thus the fossil record here does not exhibit the sort of tight, reciprocal, species-specific adaptation that shapes a hummingbird bill to fit its favorite flower – and vice versa. Rather, predator-prey "arms races" are often more of a "diffuse" coevolution in which whole suites of prey adapt in general ways to whole suites of predators, and vice versa. Vermeij dubs this "escalation": Prey evolve ever more sophisticated defenses, yet there is no "progress" in it, for predators tend to keep pace.

References:

Vermeij, G. J. (1987). *Evolution and escalation: An ecological history of life.* Princeton, NJ: Princeton University Press.

Endler, J. A. (1991). Interactions between predators and prey. In J.R. Krebs & N. B. Davies (Eds.), *Behavioral Ecology: An Evolutionary Approach* (3rd ed.). Oxford, UK: Blackwell Scientific.