Phenomena to Help High School Students Understand the Mechanism of Natural Selection

Luli Stern, AAAS Project 2061

Abstract

Much of science involves finding patterns in observations and explaining them in terms of a small number of principles or ideas. For students to appreciate how science works, they need to have a sense of the range of observations (phenomena) that are used to form the patterns and the helpfulness of the principles or ideas in explaining them. Project 2061's evaluations of science textbooks revealed that textbooks rarely engaged students with phenomena relevant to important science ideas, rarely included phenomena that directly address the often incorrect ideas that students may already have, and rarely guided students in reconciling phenomena with scientifically accepted ideas (Kesidou & Roseman, 2002; Stern & Roseman, 2004; American Association for the Advancement of Science [AAAS], 2002, 2005). In response to these deficiencies, Project 2061 and other CCMS researchers are identifying phenomena that could be used to support the teaching and learning of ideas recommended in *Benchmarks for Science Literacy* (AAAS, 1993) and in *National Science Education Standards* (National Research Council, 1996).

This poster presents a phenomenon that could be used to challenge high school students' naïve idea about the inheritance of acquired traits and another that could be used to make the mechanism of natural selection more plausible for students.

Key Idea

Natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every population, and some of these characteristics give individuals an advantage over others in surviving and reproducing. The advantaged offspring, in turn, are more likely than others to survive and reproduce. Thus, the relative proportion of individuals that have advantageous characteristics will increase with each generation. (based on benchmark 5F/H3)

What Students Are Expected to Know

This key idea explains changes occurring in populations of living things over a very long time. Students should know that:

- There is **variation** within every population.
- In given environmental conditions, some characteristics provide an **advantage** in survival or reproduction to the individuals bearing them.
- The **environment** does not cause changes in individuals; rather, it increases the chance of survival and reproduction for the more fit individuals over the less fit.
- The trait affecting fitness is **inherited**.
- The change in the proportion of individuals with a particular advantageous trait is **gradual**, taking place over several generations.

Ideas Students Have

Question	Students' naïve idea	Scientifically accepted idea
How do **populations** change over time?	By a gradual change in traits of **all** members of a population.	By an increase in the relative **proportion** of individuals that have advantageous characteristics.
What happens to **individuals** following changes in the environment?	Individual organisms can **deliberately** adapt their traits to changes in the environment (for example, by use or disuse of certain organs).	Individuals that **already have** certain traits are more likely than others to survive and have offspring.
Are **traits** acquired during an individual's lifetime inherited?	Acquired traits are sometimes passed on to the offspring. Especially when they provide an **advantage** in survival or reproduction.	The experiences an organism has during its lifetime can affect its offspring **only if the genes** in its own sex cells are changed by the experience.
How do the **environmental conditions** affect populations?	The environment **causes** changes.	The environment **selects** from existing variants that have advantageous characteristics.

Implications for Instruction

- To help students move toward seeking alternative explanations, their naïve ideas about phenomena need to be challenged first by actual experiences that counteract their predictions.
- To help students make sense of the generalization stated in the key idea, they need to be introduced to a range of multiple and varied phenomena. This range includes different types of organisms (animals, plants, microorganisms, humans) and various heritable characteristics that can be observed at different levels—that is, molecular and whole-organism levels—in structure, chemistry, or behavior.

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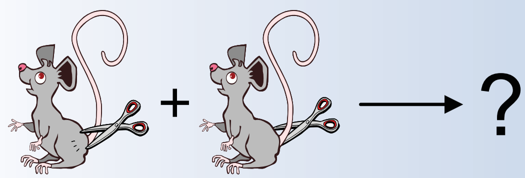
Students believe that traits acquired during an individual's lifetime are sometimes passed on to their offspring. This naïve idea may, in turn, hinder their understanding of the theory of natural selection, leading to beliefs concerning the inheritance of environmentally-induced characteristics over several generations. To address this commonly held idea, students are asked to predict the outcome of an experiment carried out by a scientist at the beginning of the 20th century showing that acquired traits (in this case, shortened tails) are not inherited. Students then compare their predictions to the actual outcomes.

Weissman's experiment: A phenomenon that counteracts students' naïve ideas

August Weissman studied whether traits that are acquired by organisms during their lifetimes are inherited by their offspring. To do so, he cut off the tails of mice (as represented below). He then allowed the tail-less mice to reproduce and cut the tails off of their offspring too. He continued to do so for approximately 60 generation.



- Would you expect the tails of the first generation offspring to be:
  - Approximately the same length as those of the parents' original tails
  - A little shorter than the parents' original tails
  - Much shorter than the parents' original tails
  - Almost as short as the parents' tails after they have been cut

  Explain your answer.
- How do you think the tails of the offspring would look after cutting the tails off of the mice for the next 60 generations?
  Select one of the choices above and explain your answer.
- Weissman cut the tails off of mice for 60 generations. How do you think the tails of the offspring would look if Weissman had continued cutting the tails off of the mice for the next 200 generations? Select one of the choices above and explain your answer.

Teacher's notes:
Nearly all students think that the tails would not be any shorter after one generation. Nonetheless, following 60 or 200 generations, many students think that the offspring would be born with slightly shorter tails. Encourage the students to explain why they think the tails would not change after one generation but would get shorter after 60 or 200 generations. At the end of the discussion, tell students that Weissman saw that in each subsequent generation, the tails of the offspring were about the same length as those of their parents' original tails.

References:

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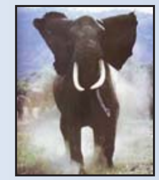
While it is obviously difficult to engage students in direct observations of natural selection, students can read about experiments or documented examples of natural selection in action.

Elephants' tusks affect survival and reproduction

Tusks are the greatly enlarged and protruding upper teeth of elephants. Elephants use their tusks to dig for food or to fight against potential predators or against other elephants. Tusks are especially important when male elephants fight with each other over females. Tusk-less elephants mate far less than elephants with long tusks. The presence of tusks and their size are heritable traits.



- Which males are more fit? Would you expect these males to be more fit in any environmental conditions?
- In most elephant populations in nature, the proportion of individuals that have tusks is higher than those without tusks. Explain this using the natural selection mechanism.

The demand for elephants' tusks has increased in the past decades. Elephant ivory has been used in huge amounts to make billiards balls, piano keys, jewelry, and many other items. Many elephants are hunted and killed every year to satisfy the demand, and the longer their tusks are, the more attractive these elephants are to the hunters. Thus the hunting, which has been going on for the past seventy years, constitutes selective pressure on the elephants. This is in addition to the selection operating on male elephants because of competition for the females. In some nature reserves in Africa, elephant hunting is restricted while in others, it is not.

- Which males would be more fit in nature reserves where hunting is restricted?
- Which males would be more fit in nature reserves where hunting is not restricted?
- What is the composition of the elephant population today, after several decades of hunting (and a few generations of elephants) in natural reserves where the hunting is not restricted?

Teacher's notes:
This example shows that various selection pressures may act upon populations concurrently, sometimes in opposing directions. Some students have difficulty identifying the two selection forces, hunting and competition for females, that exert selective pressure on the elephants. It is important that students realize that these are opposing forces: Elephants with longer tusks are advantaged during battles with other males; nonetheless, they attract the hunters.

Expanding the range of phenomena

If we want students to appreciate the explanatory power of this key idea, it is essential to provide them with a range of phenomena that the idea can explain. Phenomena should be sequenced progressively so that more complex phenomena (e.g., resistance of bacteria to antibiotics) follow the simpler ones (e.g., salmon size in the Atlantic Ocean). Relevant phenomena include (Stern et al, 2005):

- Tusk size of elephants in Africa
- Salmon size in the Atlantic Ocean
- Coloration of guppies in Venezuela
- Coloration of peppered moth in England
- Size of antlers of big horn sheep in Canada
- Beak size of finches in the Galapagos
- Length of tail feathers in male swallows
- Hit-and-run behavior of mosquitoes in Africa
- Time length of flashing in male fireflies
- Resistance of lice to anti-lice shampoos
- Resistance of bacteria to antibiotics
- Resistance of plants (grass) in England to copper
- Resistance of cancer cells to chemotherapy