Activity 2

The Formulation of Explanations: An Invitation to Inquiry on Natural Selection

This activity uses the concept of natural selection to introduce the idea of formulating and testing scientific hypotheses. Through a focused discussion approach, the teacher provides information and allows students time to think, interact with peers, and propose explanations for observations described by the teacher. The teacher then provides more information, and the students continue their discussion based on the new information. This activity will help students in grades 5 through 8 develop several abilities related to scientific inquiry and formulate understandings about the nature of science as presented in the *National Science Education Standards*. This activity is adapted with permission from *BSCS: Biology Teachers' Handbook*.

Standards-Based Outcomes

This activity provides all students with opportunities to develop the abilities of scientific inquiry as described in the *National Science Education Standards*. Specifically, it enables them to:

1. identify questions that can be answered through scientific investigations,
2. design and conduct a scientific investigation,
3. use appropriate tools and techniques to gather, analyze, and interpret data,
4. develop descriptions, explanations, predictions, and models using evidence,
5. think critically and logically to make relationships between evidence and explanations,
6. recognize and analyze alternative explanations and predictions, and
7. communicate scientific procedures and explanations.

This activity also provides all students opportunities to develop understandings about inquiry, the nature of science, and biological evolution as described in the *National Science Education Standards*. Specifically, it conveys the following concepts:

1. Different kinds of questions suggest different kinds of scientific investigations.
2. Current scientific knowledge and understanding guide scientific investigations.
3. Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
4. Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
5. Species evolve over time. Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection of those offspring better able to survive and leave offspring in a particular environment.

Science Background for Teachers

Many biological theories can be thought of as developing in five interrelated and overlapping stages. The first is a period of extensive observation of nature or analyzing the results of experiments. Darwin's observations would be an example of the former. Second, these observations lead scientists to ponder questions of "how" and "why." In the course of answering these questions, scientists infer explanations or make conjectures as working hypotheses. Third, in most cases, scientists submit hypotheses to formal, rigorous tests to check the validity of the hypotheses. At this point the hypotheses can be confirmed, falsified and rejected (not supported with evidence), or modified based on the evidence. This is a stage of experimentation. Fourth, scientists propose formal explanations by making public presentations at professional meetings or publishing their results in peer-reviewed journals. Finally, adoption of an explanation is recognized by other scientists as they begin referring to and using the explanation in their research and publications.

This activity focuses on the second and third stages in this brief summary of the development of biological theories. Chapters 2 and 3 of this document provide further discussion of these points. Review the "History and Nature of Science" and "Science as Inquiry" sections of the *National Science Education Standards* for further background on scientific investigations.

Materials and Equipment

None required.

Instructional Strategy

Engage Have the students work in groups of two or three. Begin by engaging the students with the problem and the basic information they will need to formulate a hypothesis.

TO THE STUDENTS: A farmer was working with dairy cattle at an agricultural experiment station. The population of flies in the barn where the cattle lived was so large that the animals' health was affected. So the farmer sprayed the barn and the cattle with a solution of insecticide A. The insecticide killed nearly all the flies.

Sometimes later, however, the number of flies was again large. The farmer again sprayed with the insecticide. The result was similar to that of the first spraying. Most, but not all, of the flies were killed.

Again within a short time the population of flies increased, and they were again sprayed with the insecticide. This sequence of events was repeated five times; then it became apparent that insecticide A was becoming less and less effective in killing the flies.

Explore Imagine that the farmer consulted a group of student researchers. Have the student groups discuss the problem and prepare several different hypotheses to account for the observations. They should share their results with the class. Students might propose explanations similar to the following:

1. Decomposition of insecticide A with age.
2. The insecticide is effective only under certain environmental conditions—for example, certain temperatures and levels of humidity—which changed in the course of the work.
3. The flies genetically most susceptible to the insecticide were selectively killed. (This item should not be elicited at this point or developed if suggested.)

TO THE STUDENTS: One farmer noted that one large batch of the insecticide solution had been made and used in all the sprayings. Therefore, he suggested the possibility that the insecticide solution decomposed with age.

Have the student groups suggest at least two different approaches to test this hypothesis. The students may propose that investigation of several different predictions of a hypothesis contributes to the reliability of the conclusions drawn. In the present instance, one approach would be to use sprays of different ages on different populations of flies. A quite different approach would consist simply of making a chemical analysis of fresh and old solutions to determine if changes had occurred.

TO THE STUDENTS: The student researchers made a fresh batch of insecticide A. They used it instead of the old batch on the renewed fly population at the farmer's barn. Nevertheless, despite the freshness of the solution, only a few of the flies died.

The same batch of the insecticide was then tried on a fly population at another barn several miles away. In this case, the results were like those originally seen at the experiment station—that is, most of the flies were killed. Here were two quite different results with a fresh batch of insecticide. Moreover, the weather conditions at the time of the effective spraying of the distant barn were the same as when the spray was used without success at the experiment station.

Stop and have the student groups analyze the observations and list the major components of the problem and subsequent hypotheses. They might list what they know, what they propose as explanations, and what they could do to test their explanations. Students might identify the following:

1. Something about the insecticide.
2. The conditions under which the insecticide was used.
3. The way in which the insecticide was used.
4. The organisms on which the insecticide was used.

TO THE STUDENTS: So far our hypotheses have had to do with just a few of these components. Which ones?

The hypotheses so far have concerned only "something about the insecticide" and "the condition under which the insecticide was used," items 1 and 2 above.

TO THE STUDENTS: The advantage of analyzing a problem, as we have done in our list, consists in the fact that it lets us see what possibilities we have not considered.

What possibilities in the list have we not considered in forming our hypotheses?

Item 3, "the way in which the insecticide was used," may be pursued as a further exercise if the teacher so wishes. However, emphasis should be placed on Item 4, "the organisms on which the insecticide was used." This item is developed next.

Explain TO THE STUDENTS: Let us see if we can investigate the interactions between insecticide A and the flies. From your knowledge of biology, think of something that might have happened within the fly population that would account for the decreasing effectiveness of insecticide A.

The students may need help here, even if they have learned something about evolution and natural selection. Here is one way to help:

Ask the students to remember that after the first spraying, most, *but not all*, of the flies were killed. Ask them where the new population of flies came from—that is, who were the parents of the next generation of flies? Were the parents among the flies more susceptible or more resistant to the effects of insecticide A? Then remind them that the barn was sprayed again. If there are differences in the population to insecticide A susceptibility, which individuals would be more likely to survive this spraying? Remind them that dead flies do not produce offspring—only living ones can. The students might thus be led to see that natural selection, in this case in an imposed environment (the presence of the insecticide), might have resulted in the survival of only those individuals that were best adapted to live in the new environment (one with the insecticide). Because this activity centers on the formulation of explanations, it is important to introduce students to the scientific process they have been using. Following is a discussion from the *National Science Education Standards* that can serve as the basis for the explanation phase of the activity.

Evidence, Models, and Explanation[4]

Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.

Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.

Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical statements. Different terms, such as "hypothesis," "model," "law," "principle," "theory," and "paradigm," are used to describe various types of scientific explanations. As students develop and as they understand more science concepts and processes, their explanations should become more sophisticated. That is, their scientific explanations should more frequently include a rich scientific knowledge base, evidence of logic, higher levels of analysis, greater tolerance of criticism and uncertainty, and a clearer demonstration of the relationship between logic, evidence, and current knowledge.

Elaborate Give the students a new problem—for example one of the investigations from *The Beak of the Finch* or *Darwin's Dreampond*. Have them work in groups to propose an explanation. The students should emphasize the role of hypotheses in the development of scientific explanations.

Evaluate Have the students consider the following case. Suppose a group of farmers notices the gradual acquisition of resistance to insecticide A over a period of months. They locate two other equally powerful although chemically unrelated insecticides, insecticides B and C. The local Agriculture Department sets up a program whereby all the farmers in the state will use only insecticide A for the current year. No one is to use insecticides B or C. The following year, everyone is directed to use insecticide B rather than insecticide A. The fly population, which had become resistant to insecticide A, is now susceptible to insecticide B and can be kept under control much more thoroughly than if the farmers had continued using insecticide A. At the beginning of the third year, all of the farmers begin using insecticide C, which again reduces the fly population greatly. As the fourth year begins, insecticide A is again used, and it proves to once again be extremely effective against the flies.

Have students analyze this situation and propose an explanation of what has happened. How would they design an investigation to support or reject their hypothesis?