The Process of Science

Although inquiry-based learning does not require that students actually carry out experiments, allowing your students to design and carry out experiments is an excellent way to begin to train them to think like scientists. Using the insects that you are rearing in your classroom in simple experiments provides an ideal opportunity to introduce students to scientific experimentation. If you have another preferred format for teaching students to do experiments, it will be easy to incorporate the insects into that format. If not, this section should help. For all experiments, we suggest the following format.

1) Question

What is it that you would like to learn? Students will come up with excellent questions as they observe their insects, and you may be able to design experiments to answer their questions. If this happens in your classroom, take advantage of the opportunity and follow your students' lead. However, young students may not come up with questions that are readily amenable to classroom experimentation. In this case, you may want to suggest the questions provided in this section or those of your own choosing.

After students have had time to observe and become familiar with an organism, they can move into the experimental process. This strategy helps students generate ideas for experiments by guiding their thought process from the general (what do I want to learn about?) to the specific (what variable will I change and how?). As students do this, they will learn the concepts of *independent* and *dependent* (or *response*) *variables*. A characteristic whose value may change, vary, or respond when manipulated experimentally is called a dependent variable. Conversely, something that affects the characteristic of interest is called an independent variable. The dependent variable is the one students will study. These concepts will be used again as students' design

experiments. If you would rather not use these scientific terms with your students, you can decide to use other terms to explain the same concepts.

2) Hypothesis

The common definition of a *hypothesis* is a **prediction or an educated guess** about what might happen in an experiment. However, a more accurate definition is that a hypothesis simply describes one possible outcome to an experiment, or one possible answer to your question. Hypotheses are statements that can be tested through experimentation or observation; they can be disproved or supported by evidence that you collect. Scientists regularly use *multiple hypotheses* when conducting experiments. Using multiple hypotheses teaches children that there are several possible outcomes to any experiment, and these hypotheses will either be supported or not supported by the data. One hypothesis that should always be considered is the *null hypothesis*. This acknowledges that there might not be an effect of the independent variable on the dependent variable.

Encouraging students to generate multiple hypotheses before they conduct an experiment is not only a better representation of how scientists work, it is also a way to help students avoid feeling like they were "wrong" if the experiment doesn't turn out the way they expected it to. In general, hypotheses clarify the question being addressed in an experiment, help direct the design of the experiment, and help the experimenters (students) maintain their objectivity.

3) Methods
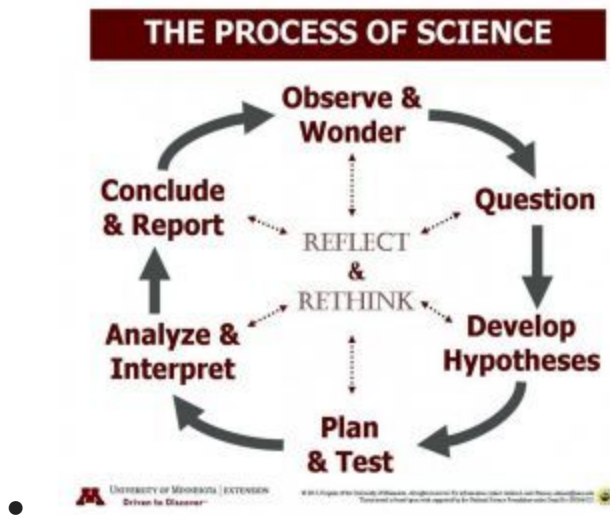
The Process of Science (Photo: Andrea Strauss)

After generating hypotheses, students are ready to design an experiment to test their hypotheses. This is a time to pay close and careful attention to all the details—both before starting the experiment and during the period of data collection. The steps described below will help students think of as many details as possible when planning their experiments. There are two important scientific concepts to discuss with your students before they design their experiments: 1) replication or sample size and 2) constant conditions. In addition, students that are doing experimental studies will need to consider a third concept: the control treatment.

Replication, or Sample Size

The best way to explain *replication* is to use an example. Let's say a scientist is interested in how many children there are in different families. Her hypothesis is that families who live in cities have fewer children than families who live on farms. If she only counts the children in one city family and one farm family, random chance will affect her results. She might happen to pick two very large families, two very small families, a large farm family and small city family, or any other combination. If, instead, she counts the children in 100 farm families and 100 city families, she will get a much better picture of the average number of children in farm vs. city families. Scientists have to use a large enough sample size to accurately test a hypothesis, while taking into account things like cost, availability of experimental subjects, and time. With younger students, however, the scientific "truth" may not be our highest priority. We want students to understand the process and enjoy themselves. If more replicates become tedious, then keep it simple. The concept of how to go about answering a question may be more important than the veracity of the results in some situations. You can always discuss how additional replicates could affect your results and conclusions.

Constant Conditions

The second scientific concept to consider is the importance of **holding everything but the independent variable constant**. For example, if you want to study temperature effects on monarch growth, the larvae must be the same age, kept in the same size and type of cage under the same light conditions, and given the same type and amount of food and water. This is an essential part

of an experiment. Likewise, the scientist studying family size wouldn't want to study farm families where the parents were 40-50 years old, and city families where the parents were 25-35 years old.

Controls

Again, we will use an example to illustrate this concept: Let's say that you want to test the hypothesis that loud music causes high mortality in earthworms. Your students may suggest keeping a group of earthworms in a room with loud music going constantly. However, if all the earthworms die, you won't know if the music killed them, or if there was something wrong with the earthworms in the first place. In this experiment, you need a *control*. Place half of the group in a "normal" environment (control group), and half in with the loud music (experimental group). If more die in the room with the loud music, your hypothesis is supported. Again, it is important to hold constant conditions between the two groups. The conditions the earthworms are exposed to in the two groups should be as similar as possible. Controls are rarely necessary in observational studies, when you're studying naturally-occurring variation. They are also not always needed in experimental studies, but if you are subjecting living organisms to extreme conditions of any kind, you should always include a control group that is not exposed to these conditions.

The fact that not all experiments need controls is illustrated by the following example. If you want to find out if the earthworm density is the same under pine trees as deciduous trees, you can simply measure the density in the two soils and compare them. There is no need to have a separate control treatment in which earthworms aren't under either pine trees or deciduous trees. However, you do want to hold other conditions constant. For example, you wouldn't want to sample the earthworms under the pine trees just after a rainy day unless you also sampled the deciduous tree worms on the same day.

4) Results

Describing and understanding the results of an experiment are critical aspects of science. There are three parts to this lesson: making a data table, making graphs, and analyzing data with simple statistical tests. You can choose any or all of these parts, depending on your instructional goals. If you have access to computers, you can use a spreadsheet program such as Microsoft Excel for all three parts. However, students should also practice making tables and graphs "by hand."

Once students learn how to make organized data tables and graphs, they should use this knowledge to present the results of their insect, plant or schoolyard studies. They will need help as they do this, but going through this lesson will give them valuable practice.

5) Conclusions

After conducting an experiment and analyzing the results, students should come to some conclusion as to what their results told them about the answer to their question. Sometimes this conclusion will be quite easy to put into words: for example, *Caterpillars prefer milkweed to apple leaves*. However, students may think that their results may need to be qualified: for example, *Caterpillars seem to prefer milkweed to apple leaves, but all of the caterpillars we tested had only been fed milkweed leaves before we used them in the experiment. This may have affected our results.* In any case, a conclusion should reflect what students have learned by doing the experiment.

The RERUN Method

RERUN

The ***RERUN method*** is one method of writing conclusions. RERUN is a short paragraph used to summarize the results from a scientific study. The RERUN paragraph should be a minimum of five well-written, complete sentences. RERUN is an acronym for five types of information that a conclusion should include:

- **R = Recall:** Describe what you did briefly.
- **E = Explain:** Explain the purpose of the study.
- **R = Results:** State the results, including which hypothesis was supported by the study.
- **U = Uncertainty:** Describe uncertainties that exist, if any.
- **N = New:** Write two new things you learned.