Chapter 15

Doing Your Own Science: A Model for Student-based Inquiry

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Introduction

Much of the excitement of scientific investigation comes from personally making observations that stir curiosity, posing questions of Why?, How?, When?, or Where?, dreaming up explanations, and then finding out which explanations actually answer the questions. Laboratory and, especially, field classes present the opportunity to make and explore interesting observations because they provide the time and conditions in which one can be observant, develop explanations for observed phenomena, design experiments, and actually carry one or more of the experiments to reasonable completion. Because they require minimal equipment and inexpensive supplies, ecological questions about patterns or activities of organisms are particularly suitable for student investigations. The student only needs the opportunity to explore in a natural setting. For the teacher, a comfortable familiarity with the inquiry process and knowledge of the natural history of the habitat are required.

Doing Your Own Science

We have used this as an introductory exercise in both a field-based, experimentally-oriented senior course in marine biology and in a workshop designed to encourage science teachers to use exciting but low tech research as a teaching tool in their classroom. This exercise even precedes any formal presentation (or restatement of) the fundamentals of the scientific method. Rather, the instructor guides the progression of research activities in a logical sequence using Socratic dialogue. We find that the often stilted and abstract formal rules of scientific method are much more readily and convincingly grasped once the students have actually performed the process. In addition, the students intrinsically comprehend concepts such as falsifiability, multiple hypothesis testing, controls, and replication as they are doing their research. The exercise is remarkably effective in exciting the participants about their research because they are directly involved in all aspects of it, from making the original observations and developing the methods of research through analyzing and interpreting their *own* data. This enthusiastic response contrasts sharply with the lackluster attitude students often maintain toward assigned exercises based on someone else’s question using prescribed techniques, none of which have emerged from the students' own intellectual investments.

Our approach can be adapted readily to any natural setting--it is merely the process of conducting scientific inquiry on a question that the *students* devise. Providing the opportunity to discover an answer through doing science is one of the most sure-fire ways to capture attention, sustain interest, and assure understanding.

Goals

The goal of this exercise is to introduce students, through actual experience, to the process of scientific investigation, including making original observations, developing multiple hypotheses, testing predictions through experimentation and further observation, evaluating data, and drawing inferences. Through this exercise, students will develop greater self confidence in their ability to use the scientific method to discover information about the natural world.

Objectives

Upon completion, students should be able to:

- describe the process of scientific investigation, including observation, devising hypotheses and logical, testable predictions, experimentation or further observation, data evaluation, and inferring conclusions; and
- when presented with the opportunity to make personally original observations, produce a set of hypotheses and a plan for testing them.

Materials

To perform the exercise, one must have:

- access to the marine environment (or other natural habitat) and
- various supplies necessary for projects or experiments.

  We use:

  monofilament fishing line
  cyanoacrylate glue (such as Superglue™)
  hand lenses
  flagging tape
  waterproof marking pens
  meter sticks
  calipers
  large and small finger bowls
  fish tanks or water tables with running seawater
  baling wire
  waterproof paper/notebooks and pencils
  scissors
  razor knives

Note that this sort of work rarely requires specialized equipment, making it easy to stock up and cheap to run.

Notes for the Instructor

Conducting the Research

In our version of this exercise, we make use of the near-pristine salt marsh habitat of coastal north Florida, allowing students to explore under the guidance of instructors knowledgeable of the flora and fauna of this habitat. Through exploration, the students make and record observations of the presence, behavior, distribution, and abundance of the organisms they find. The instructors guide the students' observation and answer questions about the organisms they see (taxonomy, common names, life cycle, etc.) but are careful not to provide quick answers to "Why?" questions, instead posing the question, "Can you think of some possibilities?"

Among the commonly seen animals are blue crabs (*Callinectes sapidus*), crown conchs (*Melongena corona*), fiddler crabs *(Uca* spp.) and various fishes such as killifish (*Fundulus* spp.) and sheepshead minnows (*Cyprinodon variegatus*). The instructors also subtly direct the students' attention to a species of small (~2 cm shell length) intertidal snail, the saltmarsh periwinkle (*Littorina irrorata*), that can be seen ascending above the water surface and holding fast to the emergent blades of the saltmarsh cordgrass (*Spartina alterniflora*) as the tide rises, then crawling down the grass stems as the tide falls.

Following this period of exploration, the students are gathered and each student is asked to comment on interesting creatures and phenomena they witnessed and to wonder about what they have seen. The instructor moderates the conversation and presents the students with the challenge of selecting one observation that will provoke interesting questions that can be examined through experimental manipulation. During the dialogue, the instructor subtly directs attention to the climbing periwinkle, directing the group to speculate on what possible biological advantage there might be for the snails to ascend the cord grass as the tide rises. Frequently, one of the students spontaneously raises just that question with little direction from the instructor at all! A list of possible reasons suggested by the students is then assembled on the board or overhead projector screen. This list predictably includes:

- to feed or search for food,
- to mate,
- to prevent being washed offshore by waves or the falling tide,
- to prevent drowning,
- to avoid marine predators that might come in with the tide, and
- to avoid osmotic stress that might be suffered in the salt water.

Note that posing these hypotheses requires only a basic knowledge and understanding of biology. Although other, more sophisticated possibilities exist, this readily tested array includes examples that are clearly supportable, falsifiable, or inconclusive requiring further study.

At this step it is tempting to begin defining terms for the students, pointing out that they have just developed *multiple hypotheses* that are *testable* and *falsifiable*, but at this point, such a discussion does little to advance the students understanding of the process. We have found that is best to continue moving forward in developing research questions and methods rather than engaging in a philosophical lecture on the process of science. There will be time when the research is complete to assign terms to each stage of the exercise and to discuss the philosophical underpinnings of the scientific method.

Once the students' ideas for hypotheses are exhausted, the class is divided into small groups, each of which selects one potential explanation and designs an experiment or set of measurements that will show whether the explanation is true or not. As the students are developing methods, the instructor and teaching assistant circulate among them, providing advice on techniques and experimental design, while allowing the students free reign in their ideas. Many times it is a matter of the students choosing from among several possible methods about which the instructor has presented the relative or inherent attributes. In such a way, the best choice can be made clear to the students, but it is still the *students* who make the choice. In this manner, the students maintain complete intellectual “ownership” of the entire process which, in turn, allows them to gain the most benefit from the exercise.

Implementing the experiments is the next stage in the process. For example, one group revisits the salt marsh hourly as the tidal level changes to observe further and to record the behavior of the snails, which are scrutinized with a hand lens to determine if the snails are feeding, mating, or engaged in some other activity. Another group may stake periwinkles on bare substrate or among the grass stalks to compare the rate of predation/death when the snails are restricted from climbing and when they are allowed to climb. Another group may subject the snails to a dilution series of saltwater for various durations to determine the snails' salinity tolerance and resistance to drowning. Yet another group compares the ability of snails to hold position when subjected to waves or different rates of water flow while on sand and on grass. In this way, all of the hypotheses are investigated.

Once the projects are completed, the data analyzed, and statistics compiled, the entire group reassembles in seminar format to present results and draw conclusions. Through this interchange, the students will likely determine that the snails staked in the sand and not allowed to climb the grass suffered significantly greater death by predation from blue crabs (i.e., snail shell broken or tether cut) and the Florida crown conch (periwinkle shell empty or now inhabited by a hermit crab!) than those that were able to climb up the cordgrass and out of the water. It is further likely that no snails drowned or expired in any of the salinities (they tolerate a wide range of salinities by sealing themselves in behind their operculum and can survive for longer than the period of a high tide in such a manner) and that no significant activity occurs among the snails that have climbed the grass. It will also be clear that snails are easily displaced by currents when on sediment but not when on grass. However, the lack of an accurate assessment of the range of natural conditions and situations and the effects of longer duration exposures, etc., will leave some of these results inconclusive. The students are then familiarized with the work of Warren (1985) and that of other authors cited in her paper, investigating the same periwinkle snail climbing behavior.

Summarizing the Scientific Method

It is at this point, once the project is complete, that the instructor finally leads the whole group to reflect upon the process of inquiry that they have just completed. The instructor assigns and discusses the appropriate, formal terms of each step:

- making observations,
- developing multiple hypotheses that are testable and falsifiable,
- designing experimental protocols or sampling methods to test hypothetical predictions (such as using controls, replication, and independent samples),
- evaluating data and sources of variation, and
- assigning different levels of strength of inference.

It is valuable to provide references concerning experimental design and the scientific method, as well. We are particularly fond of the seminal work published by Chamberlain (1897) on multiple hypotheses (it was reprinted in *Science* in 1965) and the guide provided by Carey (1994).

Reinforcing Activity

We like to use, at the next available opportunity, a reinforcing exercise in which pairs of students are given the task of making a new observation and performing follow-up research on their own with the instructor acting only as a technical consultant and critic. The initial exercise demonstrates to the students that they can successfully do science, and this follow-up exercise provides an opportunity for them to gain more experience, confidence, and greater competency. In this follow-up exercise, the emphasis remains on the students pursuing questions that they pose themselves (and are therefore intrinsically interesting and motivating) even though the phenomenon under examination may be well understood in the scientific literature. Remember, at this novice stage, it is the inquiry process that is at issue. Later on, one can focus on subject knowledge and integrate it with student research.

Adapting this Exercise

We chose to capitalize on a readily accessible coastal habitat that we know much about. Yet the exercise could just as well be done at pondside or in a weedy field focusing on plants, ants, or tadpoles. We suggest you become (if you are not already) a curious naturalist and develop a deep knowledge, from the literature and local field study, of an available habitat near you. Most campuses have a nearby natural site that can provide a setting for the type of non-destructive exploration that is modeled in this activity.

We have found that, at least for the initial exercise, it is best that you have pre-tested the process and techniques that the students are likely to use for their experimentation. By knowing what does and doesn't work, you can help guide the students into the experimental designs that are most likely to work and significantly reduce their risk of experimental failure--that is, an experiment that provides no interpretable results. As you create a situation in which the students have apparent control of the questions and the methods for research, yet are working within a 'tried and true' system, you can provide them with an initial success in experimentation. Such a success will help the students develop a stronger sense of their own abilities as budding scientists. This success will prepare the students to accept the risk of failure that is inherent with any completely new experimental design. Through these activities the students discover the real joy of scientific exploration. With some planning and preparation on your part, you can pave the way to lead students down scientific inquiry's 'garden path' effectively.

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