CHAPTER 7

The Process Skills of Inquiry
by Doris Ash

By being aware of the parts that make up the whole, a teacher can help children learn the skills necessary to plan and carry out successful inquiry investigations. While the inquiry process can be represented in many different ways, this chapter gives one interpretation that can help teachers identify and use the valuable "process skills" of inquiry.

> "When education is viewed as inquiry, important things happen. The focus of education becomes learning and the task of teaching becomes one of supporting the inquiry process."
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> —*Harste (1993)*

Imagine kindergarten children exploring how potatoes grow. The children start by carefully looking at potatoes. One of the first things they notice is that the potatoes have sprouts. They wonder about the sprouts and what they might do. The teacher elicits more observations and questions. Among other things, the children suggest that potatoes grow under the ground. They wonder if potatoes have seeds, and what a potato seed might look like.

The teacher helps the children generate a list of their questions:

- What is a sprout?
- How can you get plants without planting seeds?
- Do the sprouts have anything to do with getting new potatoes?
- Should we plant all or part of the potato?

In order to answer some of these questions, the teacher suggests that students investigate in more detail. Based on their questions and observations, he organizes the children into similar interest groups so that they can work together in small groups of two or three. The teacher then asks the students to begin by creating a plan that includes a list of the materials they think they will need and drawings of what they will put into the dirt—a whole potato, half a potato, the part with or without a sprout, and so on. The child who wondered about the seeds wants to include seeds in his plan. On his own, he has found a book in the classroom that supports his theory that potatoes have flowers and seeds. The teacher suggests that he research this piece after the initial experiments are underway.

Next, the children plant their potatoes according to their plans. When the plants begin to sprout, the students uproot them to look for evidence of change. They notice that some of the potatoes they planted have rotted, but others have grown. They see roots and the beginnings of new little potatoes attached to these roots under the ground. They hypothesize that the potato pieces that originally had sprouts were the ones that grew into the plants with the little potatoes attached to their roots.

The children have many more questions, and again the teacher lists these for the class.

- How long would it take to grow a larger potato?
- How many potatoes would grow from each plant?
- Can one of the new little potatoes be used to grow another potato plant?
- How much of the potato needs to be buried in order to grow a small plant?

It is near the end of the year, so the teacher suggests that the children try some followup experiments at home during the summer.

The Parts of the Process

When learners interact with the world in a scientific way, they find themselves observing, questioning, hypothesizing, predicting, investigating, interpreting, and communicating. These are often called the "process skills" of science. Process skills play a critical role in helping children develop scientific ideas.

A sometimes bewildering variety of interpretations of process skills, including their number, order, and relative importance, exists in local, state, and national science education standards. Here we suggest one possible interpretation of seven of the process skills of science (Harlen and Jelly, 1997):

- ***Observing***—watching carefully, taking notes, comparing and contrasting
- ***Questioning***—asking questions about observations; asking questions that can lead to investigations
- ***Hypothesizing***—providing explanations consistent with available observations
- ***Predicting***—suggesting an event in the future, based on observations
- ***Investigating***—planning, conducting, measuring, gathering data, controlling variables
- ***Interpreting***—synthesizing, drawing conclusions, seeing patterns
- ***Communicating***—informing others in a variety of means: oral, written, representational

Observing

Observation of real phenomena begins the inquiry process and continues throughout all its phases. For the kindergartners studying potatoes, observation, the starting point for their endeavors, also led them from one step to the next.

In making observations, the learner gathers evidence and ideas about phenomena and begins to identify similarities and differences. He may also begin to see patterns or understand the order in which events may have taken place. Close observation provides the evidence that allows ideas

"The Eyes Have It: The Growing Science Inquiry Teaching Cycle," a video by the National Gardening Association, Burlington, Vermont.

to be checked, and it therefore needs to be detailed and relevant. The learner must have confidence that her observations are valuable.

Because observation skills can more easily be developed than other process skills, they are often more consciously practiced with younger students. But, as shown above, even kindergartners have the ability to move beyond observation to other areas of investigation.

Questioning

Curiosity drives the inquiry process—it generates questions and a search for answers. In inquiry, the process of asking a series of questions is the first step in finding answers. Questioning, therefore, is the basis from which inquiry continues. It is at the heart of the inquiry process. It is a habit of mind that can be encouraged in any learning setting. An ethos of questioning in the classroom allows learners the freedom to move into uncharted territory and begin to explore what they don't know or need to better understand.

The questions the kindergartners asked about the potatoes arose from watching real phenomena in an unhurried fashion. These questions recurred regularly throughout the children's exploration. As they worked, each question led to an action, which in turn led to the use of other process skills, including asking more questions. This is the nature of inquiry, which is not a linear process.

Equally important to raising good questions is the process of selecting questions that might be followed with fruitful investigations. In the school setting, one of the most important skills we can develop is to understand better which questions can be answered by experimentation, and which cannot. Children become aware of this gradually. Part of the inquiry process is determining how to turn non-investigable questions into investigable ones, and learning how to recognize questions that are generative, long lasting, and interesting enough to foster a rich investigation.

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Hypothesizing

Our kindergartners, by their actions, suggested that perhaps the sprout itself was associated with the growth of the potato. This is a tentative explanation for the function of the sprout. It is based on available evidence, and it is, essentially, a hypothesis.

Hypothesizing suggests an explanation consistent with available observations, questions, and evidence. When a student makes a hypothesis, he links information from past experiences that may explain both how and why events occur. (See "To Hypothesize or Not to Hypothesize?" on page 61.)

Inquiry starts when something catches our interest and we take time to observe it very carefully. Hypothesizing arrives after we have an opportunity to observe, comment, raise questions, and explore with materials. We raise questions based on experience and observations and continue to gather experiences with the particular phenomenon. Along the way, hypotheses are created, but they may arrive well into the experience and act as a way of pulling together accumulated information.

Predicting

Predictions are central to the process of testing whether or not a hypothesis is on the right track. This process takes away the need for guessing. A prediction goes beyond available evidence to suggest what will happen in the future. A learner who says, "If I do this, then that will happen" has a way of finding out how something works.

There are a variety of ways to use evidence. Young children may make conclusions that are only slightly related to available evidence. Older children may use evidence in more sophisticated ways, including recognizing patterns of data from which to extrapolate or interpolate. The greater the use of evidence to link the original ideas to future behaviors, the more useful and testable the prediction.

Typically, a prediction is based on evidence from past knowledge and/or experience, and upon immediate evidence gained through observation. It is important to know how to gather evidence and how it can be used to best advantage. Predictions invite the orderly gathering of evidence for a specific purpose.

Investigating

Measuring, gathering data, and performing "fair tests" are used to gain the evidence necessary to provide a consistent interpretation. With meaningful evidence, we can answer a question or test a prediction with some certainty that the appropriate variable is being tested and systematically measured. This means the investigator is able to understand which variable will be held constant and which will be undergoing change, a concept that is often difficult for the young or inexperienced investigator.

An investigation typically takes many unanticipated twists and turns. Solving one problem may lead to another, so investigations may take many different paths. Our kindergartners experienced this as they planned their own potato investigations. One group's investigation led to a rotted potato; another group's investigation led to a healthy potato plant. In each case, meaningful information was gathered, but along different paths.

Interpreting

Once the kindergartners had done their tests, they needed help in making sense of them. They needed to get beyond the mere gathering of data and begin to interpret what they'd found.

Interpreting includes finding a pattern of effects and synthesizing a variety of information in order to make a statement about their combined meaning. It may include making associations between variables and making sure that the data support the hypothesized connections. It is critical to relate findings to initial questions and observations.

"The Eyes Have It: The Growing Science Inquiry Teaching Cycle," a video by the National Gardening Association, Burlington, Vermont.

Communicating

An inquiry classroom relies on open communication. For the students, that means talking to others, listening to their evidence and explanations, and representing their own results in a clear manner. It includes taking notes in the course of an investigation. It also includes choosing the appropriate way to translate knowledge to others, by making representations such as charts or diagrams, for example, that illustrate data and results.

Communication in the inquiry classroom goes beyond simply exchanging knowledge. It implies that socially gathered and shared information informs individual learning.

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Modeling Independent Learning

One of the most important roles of the teacher as facilitator is to gradually allow the learner to take more responsibility for the learning process. In a school setting, the process of inquiry is always guided by the teacher, who gradually transfers responsibility for aspects of the investigation to the student. Ultimately, a student who has effective guidance can learn to ask his or her own questions. The same is true for the rest of the skills that make up inquiry. Step by step, students can take on responsibility for planning, conducting investigations, using evidence, etc. As students master these skills, they can take responsibility for assessing issues for themselves, making judgments based on their assessments, taking action to initiate their own inquiries, and collecting and interpreting evidence on their own.

The gradual shift of responsibility from teacher to learner is a complex one that is at once natural and carefully designed. Over time, the teacher models the kinds of behaviors he or she would like students to learn, such as collaboration, posing questions, careful use of materials, self-reflection, and language skills. At first, the teacher is directive, acting as a guide until students demonstrate their own abilities to work independently. Like a parent modeling the complex living skills a child will need through life, the teacher models the skills and techniques of independent learning. In a process often referred to as "scaffolding," the teacher gradually fades from control of certain areas as students take on the skills in their own way.

Putting the Pieces Together

There is no one way to use a process skill. Each skill has characteristic, developmentally appropriate abilities for different ages, from novice to advanced. With practice, these abilities can be developed over time. In our potato investigation example, for instance, the kindergartners used all the process skills of science, at a level appropriate to their age.

Research suggests that some process skills are more regularly practiced in the elementary classroom than others. In particular, there may be more observation and questioning than hypothesizing and interpreting. Because all the skills are necessary to full inquiry, and because they all fit together in a coherent fashion, it is important to develop all the process skills early on.

Process skills are not used for their own sake. Rather, they are used in order to further the learning process and are an important way to link previous and current knowledge. During their investigations, for instance, the kindergarten children were observing, questioning, gathering information, and performing some initial tests that would propel them in many new directions. As students use these skills, they build up new conceptual understandings. They learn the content of science.

When doing inquiry, we assume that curiosity, respect for evidence, and a willingness to change ideas are attitudes of scientific thinking. These go hand in hand with the idea of a fair test and respect for evidence. Use of evidence involves both the processes, the content, and the attitudes of science, for it is useless to gather evidence if one does not have a willingness to change beliefs if the evidence is contrary to expectations.

The inquiry process takes advantage of the natural human desire to make sense of the world… This attitude of curiosity permeates the inquiry process and is the fuel that allows it to continue.

For children, the process of asking questions, investigating phenomena, gathering evidence, and solving problems begins when they realize that they can find things out for themselves. The inquiry process takes advantage of the natural human desire to make sense of the world. It relies on a willingness to come up with questions that reflect these interests. This attitude of curiosity permeates the inquiry process and is the fuel that allows it to continue.

In the scenario above, the children learned important scientific ideas about how plants grow and also discovered new information on their own. By linking new ideas to existing ideas, children can change conceptual models and build up a rich array of experiences. With these experiences, they can go further—making hypotheses, posing questions, making inferences, and ultimately coming to a deeper understanding of science.

To Hypothesize or Not to Hypothesize?

by Jerry Pine

As a research scientist who is involved with elementary science education, I often notice teachers recalling from their past education a "scientific method" that usually includes many attributes of scientific inquiry, among them observation, collection of data, analyzing data, drawing inferences, and reaching a conclusion. Very often this method is presented as a linear sequence of activities, which it need not be. Scientists move back and forth among processes to refine their knowledge as the inquiry unfolds. Inquiry is an artistic endeavor, and not the following of a recipe.

Frequently, the scientific method as taught by non-scientists requires that a scientific inquiry must stem from a hypothesis, which in fact is not usually true. Did Darwin board the *Beagle* with the hypothesis of natural selection in hand? Did Galileo experiment with falling bodies with the hypothesis that they would all exhibit the same acceleration? Did Mendeleev invent the periodic table based on a hypothesis that there should be one? In these three cases, as well as a great majority of other crucial scientific inquiries, there was an exploration of the unknown, with not nearly enough previous knowledge to support an initial hypothesis on which to focus the exploration.

If we don't begin with a hypothesis, then what does initiate a scientific inquiry? A question. Sometimes it can be a very specific question: "Do bean seeds germinate better in the light or the dark?" Sometimes it can be a much more general question: "How do crayfish relate to one another?" If we have a great deal of previous knowledge, we might hypothesize. After some study of electric circuits, we might hypothesize: "Two lengths of resistance wire in parallel will have less resistance than either one." But we could just as well have asked the question, "How does the resistance of two lengths of resistance wire in parallel compare to that of either one?"

We can begin every scientific inquiry with a question. If we insist on a hypothesis we will often merely force an unscientific guess. If there is a valid hypothesis it can always be stated as a question, for example, "Is it true that (insert the hypothesis here)…?"

So, the answer to our initial inquiry is: To hypothesize or not to hypothesize? Don't. Pose a question instead.

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References

Scenarios adapted from *Windows on the classroom*, a four-part video series by the National Gardening Association, Burlington, Vermont.

For more information, see the Web site at http://www.exploratorium.edu/IFI/activities/processcircus/circus.html.

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